Teaching Product Development by Deterministic Design

by

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ABSTRACT

The objective of this work was to develop a deterministic design and teaching process for the creation of new products ranging from books, to music, to consumer products. The foundation of the process is the Peer-Review Evaluation Process (PREP). The process is especially useful for diverse teams of designers with members from various cultures, races, genders and personalities. It is especially useful for helping team members who are not comfortable with verbal group brainstorming or one-on-one type interactions to contribute to the development of designs.

Projects were completed by teams largely comprised of underrepresented minority and female students using Deterministic Design with PREP. Design teams were monitored and students from six consecutive years of a design course were given questionnaires to determine the level of collaboration and designer satisfaction throughout the development process. Questionnaire responses indicate increasing levels of collaboration throughout development and above average satisfaction with the process. Students indicated that since learning the process, over 45% use PREP 75% of the time and over 75% use PREP at least 50% of the time when working with others. Three patents have been issued from products developed using this process, and one is pending. The process has been introduced to universities in South America and Europe and a teaching manual is being published. Two goals are to continue to introduce Deterministic Design with PREP to other schools, organizations, and disciplines, and to start an Urban Design Corps.

Thesis Supervisor: Alexander Slocum
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Thank God, my mom, my wife and all my family and friends... Without you, this would not be possible.

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1 INTRODUCTION

1.1 Background and Motivation

The objective of this work was to develop a deterministic design and teaching process for the creation of new products ranging from books, to music, to consumer products. The foundation of the process is the *Peer-Review Evaluation Process* (PREP)[1]. The process is especially useful for diverse teams of designers with members from various cultures, races, genders and personalities. It is especially useful in getting team members to contribute that are not comfortable with verbal group brainstorming and prefer a written format, or one-on-one type interactions.

The development of this method started by Prof. Slocum at MIT and I during my SM thesis, and evolved as I helped teach MIT courses 2.971[2], Second Summer Program Introduction to Design Workshop for the Office of Minority Education, and 2.007[3], Introduction to Design, as well as MIT special programs MITES[4] (Minority Introduction to Engineering and Science), SEED Academy[5] (Saturday Engineering Enrichment and Discovery), and NASA RISE[6] (National Aeronautics and Space Administration Research In Science and Engineering), and SP2H1, Creative Deterministic Composition: Poetry in Progress, a creative writing course I began as part of MIT's Experimental Study Group (ESG). My experience in teaching and practice, including industry, led me to the conclusion that often contributions are limited during brainstorming sessions, as people who may be perceived inferior by those in the majority fear justifying this opinion by blurting out what might be an impractical idea. However, in many situations, the majority of what is proposed during brainstorming sessions is not viable, but not contributing reduces the effectiveness of the process. A self-reinforcing problem is generated. It is

1. The design process implemented is a variant of Method 635 by Rohrbach and the Delphi Method [15], [7]. Using Method 635, six people circulate their three best ideas to the other five people for feedback. Best results in Deterministic Design with PREP have come from groups of four. While the Delphi Method calls for a panel of experts to conduct forecasting, Deterministic Design seeks forecasts from the designer's peers.
2. http://pergatory.mit.edu/2.971/
3. http://pergatory.mit.edu/2.007/
4. http://web.mit.edu/mites/
5. http://web.mit.edu/seed/
6. http://web.mit.edu/ome/RISE02

hypothesized that this problem can be overcome in the following way: a team is given a design objective, team members individually brainstorm on strategies and later concepts to resolve the objective, individuals privately write down their best ideas, they privately review each other's ideas, and then they "brainstorm" (discuss and select) as a team. We originally taught this approach because we wanted to maximize team collaboration and over time we recognized its impact as a teaching tool. Also, we assume that good education and good design practice are congruent. We believe that good education is best achieved by students doing with minimal inhibitions. We believe the same is true for design.

Three patents[7] have been issued for products developed using this process, and one is pending. The process has also been shared with la Universidad de Antioquia in Medellin, Colombia and la Universidad de Castilla-la Mancha in Ciudad Real, Spain for evaluation and possible adoption. One book of poetry and a music CD[8] have been created through the application of a derivation of this process, demonstrating its versatility. A textbook is being prepared for instruction of this derivation of the process. In addition, a large number of technical projects have been completed using Deterministic Design and PREP, including a personal design project: a chair for knee rehabilitation after total knee replacement[9].

Deterministic Design with PREP was also taught to young people at various stages of maturation. Not all of these students become designers, but the exercise contributed to their general education. It improves their communications skills in three areas: their writing skills are developed to the point that their work can be reviewed by others without verbal explanation; they become effective at reading the work of others and providing constructive criticism to help make improvements; and group discussion/brainstorming helps them become comfortable with oral communication. I believe the skills developed using Deterministic Design with PREP are transferable to other disciplines and I am adapting the process for use in other areas, including but not limited to writing, music, and grading/evaluations.

7. US Patent# 5,915,869: Ergonomic Cleaning Apparatus With Multiple Scrubbing Surfaces, US Patent# 6,641,453: B1: Construction Set For Building Structures, and US Patent# 7,040,949: Flexible Connector.
8. Journey of The Lost Souls, by Marc Graham http://www.jotls.com/
9. http://www.kneeflexer.com/

1.2 Multicultural Teams

Just as complications often arise in multicultural societies, they do so in culturally diverse design teams, as well. In my experience with multicultural teams, I have encountered language issues, trust issues, belief conflicts and more. Of the many design processes I have researched, I have yet to locate one that directly addresses its effectiveness in use with multicultural design teams. Design teams are not immune to the societal issues faced in every other facet of a diverse society. As design teams become more and more diverse, it is important that design processes accommodate for cultural differences.

1.3 Urban City Education

On-average, students from low-income families score below students from higher-income families on standardized tests [21]. A considerable difference has also been documented in standardized test score between blacks and whites [22]. Urban city schools are highly comprised of black and hispanic students from low-income families. Also, there is an increasing number of students whose first language is not English. The shortcoming of urban city education often leaves its graduates uninterested in pursuing degrees in engineering, science, and technology and even further, uninterested in completing high school. An example being students from the school districts from which students for MIT program SEED Academy are selected. The dropout rate for these schools is greater than twice that of the state of Massachusetts[10]. However, more than 93% of the first SEED Academy class[11] graduated and went on to college. Introduction of engineering principles to urban city education, particularly a design process that addresses working as part of a multicultural team, exposes students to the kind of work and work environment experienced by engineers. It may be one approach to sparking interest of high school students in matriculating to college and selecting engineering as a career choice.

1.4 Design Practices and Design Processes

There are a number of recognized definitions for design and variations of the "design process". I generally define design as being a problem solving process that entails the planning,

10. http://profiles.doe.mass.edu/home.asp?mode=o&so=-&ot=5&o=164&view=all
11. The first SEED Academy class graduated from high school in 2005. Out of 15 students, 14 went on to attend 4-year colleges and universities.

styling and development of ideas, or concepts into a working structure, or program. Design practices are techniques used throughout the design process to help progress. Design processes seek to provide a method for the development of ideas. Design practices seek to provide methods for completing each stage of the design process. Table 1-1 displays common design practices and design processes detailed in section 1.5 Related Work.

Title	Design Practice	Design Process
Method 635	X	
Delphi Method	X	
Related Stimuli	X	
House of Quality	X	
Pugh Chart	X	
QFD/TQD		X
Concurrent Engineering		X
Axiomatic Design		X

Table 1-1: Design Practices and Design Processes

In my opinion, a good design process clearly specifies the transition from one stage of the process to the next. A novice designer should be able to follow a design process to satisfactory development of an idea, as a novice cook should be able to follow a recipe to satisfactory preparation of a meal. Design practices may be applied at different stages of a design process to help enhance the work being completed.

1.5 Related Work

David Ullman in his book, *The Mechanical Design Process* [0], details many issues facing design teams and common practices for resolving them. He defines introverts and extroverts and suggests techniques they should use when working together in design teams. Essentially, these approaches require a change in behavior, as opposed to a change in process. For example, extroverts are persuaded to talk less, or after others have spoken and introverts are persuaded to talk more and share more than just their final idea. Changes in behavior or personality may be facilitated by a change in process. However, behavior modification is a difficult thing to accomplish. Furthermore, such changes without a process change may hinder the creative process, as designers will have to consider their behavior as well as development issues. As described later in this document, the Peer-Review Evaluation Process (PREP) actually lets all people participate without behavior modification. It begins with independent thought, providing time for designers to make initial developments without the influence, or interference of others.

Prior developments have led to a number of practices to improve design processes by improving quality and reducing time to market, often dependent on collaborative engineering practices. Listed below are some design practices and design processes that have influenced this research.

1.5.1 Method 635

Method 635 is a brainstorming approach developed in 1969 by Bernd Rohrbach [15]. In Method 635, a group of 6 people each independently develop 3 ideas for solving a problem, and then each person's ideas are reviewed, modified, and/or enhanced independently by each of the other team members. After 5 rounds of passing ideas, everyone's ideas have been evaluated by each team member. This process can accommodate more people and/or more ideas, though in my work with design times I have observed adding people greatly increase time to complete and often does not increase the quality of ideas or reviews (i.e. comments become immaterial and/or repetitive, generally after the third review). I have found that fewer people (four member teams) often leads to better collaboration (i.e. more detailed review from reviewers and quick progression).

1.5.2 Delphi Method

Delphi Method is a technological forecasting process, originally developed in 1968 by the RAND Corporation [7]. The Delphi Method employs a panel of experts to predict future occurrences/problems a proposed solution may face. Anonymous summaries of opinions and responses to a series of quantitative questionnaires are used to converge on the best likely approach to a solution. The median of the responses is selected as the majority opinion of the panel.

1.5.3 Related Stimuli

Related Stimuli are stimuli generated in context to the problem and used to help designers think of new ideas. An example of using related stimuli would be multiple rounds of Method 635. Several other practices for generating solution concepts are also listed in "*Product Design and Development*" by K. Ulrich and S. Eppinger [5].

1.5.4 The House of Quality and QFD/TQD

The House of Quality is a design practice for implementing customer requirements into products, while effectively weighing the proposals of all designers. The *house of quality* is built by applying "Quality Function Deployment" (QFD) [6], often referred to as "Total Quality Development" (TQD) [8], used to come up with the engineering specifications for the product. QFD/TQD compares the "state of the art" with the design in progress and strongly focuses on the customer's viewpoint. It is a tool to convert customer requirements into design specifications and quality standards to be used throughout production. All aspects of the design must be quantified in one way, or another.

1.5.5 Total Design and Pugh Charts

Total Design [3] is a process where a group of experts collaborates to identify a market, decide on a project, and design a product and the way to support users once the product is on the market. Pugh's approach was to use a table, now referred to as a *Pugh Chart*, listing all the different ideas in the top row and the comparison attributes or criteria in the left column and compare (with respect to a baseline idea) how well the ideas meet the criteria [2], [11]. A baseline idea is selected and given a score of "0" for each attribute. All other ideas are then compared giving them scores from "++" for far superior, to "+" for superior to "0" for equal to the baseline, to "-" for worse to "--" for much worse than the baseline. The "best" idea is the idea with the highest score; however that does not mean that this is the idea to use as is. Rather the goal is to then go back to the table and see which other ideas have higher individual ratings for some of the functional requirements, and then to see if their particular "++" attributes can somehow be used to support the "best" idea; thus evolving the idea into a truly "best" idea.

1.5.6 Concurrent Engineering

Concurrent Engineering details how to bring high quality products to market faster and at low cost [10]. The approach is to consider product design, business and production concurrently throughout the development process.

1.5.7 Axiomatic Design

Axiomatic Design is a design process that seeks to reduce product development risk and cost, and speed time to market by driving design developments based on identifying unique uncoupled functional requirements and making sure there are unique design parameters associated with each functional requirement. Keeping stakeholders in the loop throughout the process is also important, as in thoroughly analyzing and optimizing design architectures, providing detailed traceability from customer needs, to requirements/design logic/design, and appropriate project scheduling [23].

1.5.8 Discussion

In the mid 1990s, Professor Slocum of MIT and I started plans for an Urban Design Corps (UDC)[12]. Our goal was to develop an organization that would teach design to young people in urban areas. Promising designs would be used as a basis for the start up of companies to provide community jobs. We did not develop economic and organizational plans needed to make such an organization work; however, we have evolved the MIT Second Summer Program as an introduction to design workshop, which teaches students product design and prepares them for challenging work as summer interns. In running this program and others and through working as a teaching assistant for MIT course 2.007 (Introduction to Design and Manufacturing I), I have made observations of students practicing design as part of design teams, paying particular attention to underrepresented minorities, women, introverted, and disabled students. We found that teaching team design is generally good education, because it prepares students for all types of group work. The skills students develop in design courses are transferable to other disciplines. The observations from teaching the Second Summer Program and 2.007 are key to the development of the process presented in this thesis.

1.6 What Is In This Thesis

This thesis describes the evolution of a design process, Deterministic Design with a Peer-Review Evaluation Process (PREP), and examines team-based design projects that used this process. A number of design processes have been evaluated and it is agreed that there are various

12. http://pergatory.mit.edu/udc/index.htm

proven techniques for saving time and money. Also, it has been realized that often times all members of design teams do not fully contribute to the development process, which often works in opposition to saving time and money. It is believed that there are several reasons behind team members not fully contributing. The approach illustrated in this work addresses the issue of limited contribution and focuses on getting every team member to contribute to the design and development process.

Prior contributions to the design process help to form the basis for the proposed Deterministic Design with a Peer-Review Evaluation Process (PREP) approach, which will be used to promote uniform contributions of all members of diverse teams. PREP will realize the full value of design teams (particularly those with diverse membership), bolstering the development of new products and technologies. It is hypothesized that this work will contribute to society by advancing education and the economy to create new markets through the implementation of new products and technologies.

Discussions on how Deterministic Design with PREP was instructed to young people at different levels of maturity are also included in this thesis. The process is an effective teaching tool and prepares students for more than design work. Their communication skills are developed through the application of PREP. It also gives them an introduction to research, as they are required to analyze their proposed approaches to new developments. Their understanding of fundamentals is also reinforced through the review of the work of peers. The skills developed through Deterministic Design with PREP are transferable to other areas and this is discussed in this thesis as well.

This thesis is based on observations from years of teaching Deterministic Design with PREP. It also provides feedback from students who have learned the process, including to what extent it has helped them in design teams and to what extent they continue to use the process in their work with others. Findings from teaching the process at ordered stages of development, high school through college, are also discussed with suggestions for how to alter the process to complement preparation. Finally, there is discussion on how to further develop the curriculum.

Further studies would include effects of using Deterministic Design with PREP in actual engineering practice in the field.

1.7 Data Collection Strategies

The first approach to data collection was to conduct descriptive research to build a theory.[24] There was a desire to teach product development by Deterministic Design with PREP, but there was no real understanding of what outcomes to expect. Through observation it was noticed that on average teams using Deterministic Design with PREP took three hours less time per week (15 from 18) and as much as 7 hours less per week to design and build fully functional machines and/or products than teams using comparable development processes without PREP. When using Deterministic Design with PREP, women, minorities, introverts, and the disabled seemed more comfortable and active in design teams than before its application. Through introduction to high school students, it was observed that use of the process helped students improve mastery of concepts, as has been observed with other active learning programs.[25] Also, through descriptive research, it was found that Deterministic Design with PREP may be useful in teaching how to do creative writing for an audience[13]. Observations indicate that Deterministic Design fosters increased collaboration and satisfaction with group work. The theory behind this work is that a deterministic design process could be developed and used as a teaching tool for the creation of new products ranging from books, to music, to consumer products. Once a theory was established, Deterministic Design with PREP was taught to design students ranging from high school freshman to college seniors. Data was collected through face-to-face interviews, questionnaires, and direct observation research.

13. http://pergatory.mit.edu/jotls/cdc.htm, http://www.untoldrecords.com/

2 BROAD BACKGROUND TEAMS

This work does not seek to neutralize the effects of bias in team settings, contribution is of primary concern. Marginal contributions of team members reduce the effectiveness of teams and cut into the bottom-line. The purpose of PREP is to structure team contributions. If there is bias by the management and staff and/or team members using PREP, it is most likely rooted in a social issue and not likely to be fixed by a design process. However, we have found this process not only helpful in strengthening team member contributions, but also subduing personality conflicts that hinder development.

2.1 Introduction

Teams are strongest when each member fully contributes; as it is known, the strong survive and strength is in numbers. However, where does this leave minorities, women, introverted and disabled people? Minorities are without numbers and often feel looked down upon by the majority. Societies are also generally run by men and sometimes women are made to feel inferior. Introverts are generally uneasy about being vocal in contributing, or giving and receiving verbal feedback. Special needs of the disabled are often in contrast to spontaneous group dynamics. Race, sex, personality, and physical differences should not be allowed to hinder collective creative development. As design teams become more diverse, design processes be virtually immune to the social ills that plague diverse societies.

During the brainstorming process, many ideas presented are bad. If team members are more concerned with not presenting a bad idea than contributing to the brainstorming process, the effectiveness of the process is reduced, along with the strength of the team. Someone who already feels like an outsider is not likely to contribute, or feel comfortable contributing, because most of what anyone actually says is likely found to not be useful. Hence they would be reinforcing negative stereotypes. In an attempt to provide a design structure that allows every team member to contribute on equal terms, a Peer-Review Evaluation Process (PREP) is used [15]:

- Designers individually write down their ideas as they come to them before meeting with the team to discuss

- The team meets and ideas are passed around, as in Method 635 [15], and each person reads and makes written comments on each other's ideas (no discussion)
- Normal brainstorming discussions then occur to select and move forward

Implementing a process that allows each member to organize their thoughts and contribute before discussion takes place, gives everyone an equal opportunity to present what they have to contribute (i.e. an equal chance at being heard). Once the team is familiar with each member's approach and domain knowledge (i.e. area of expertise: physics, materials, fluid mechanics, etc.), equal participation of all members is invited. Extroverts will voice their contributions, because it is in their nature to do so. However, those who are introverts, for whatever reason (race, sex, personality, or condition), will also be invited to contribute, as their value is well known and documented by the team.

A complete design process accounts for all work related factors that affect the design team and consequently outcome of the product. In his book *"Product Design and Development"* [0], David Ullman defines the design process as the organization and management of people and the information they develop in evolving a product. He also states that the success of a design process can be measured by the cost of the design effort, the cost of the end product, the quality of the end product, and the time needed to develop the product. All these factors can be influenced by team chemistry, which is often times imperfect on diverse teams. Because of prejudice and the influence of stereotypes, the domain knowledge or lack thereof for a teammate may be assumed based on race, or gender. In teaching high school students, I have witnessed situations where Asian team members were expected to have superior analytical skills, whereas females or underrepresented minorities were seen as lacking analytical skills, even by other females and/or underrepresented minorities. Having a design process that maximizes the contribution of each team member regardless of race, gender, or personality is a great benefit, especially when working with diverse and unbalanced groups.

Smith and Reinersten [14] state seven criteria (see Table 2-1) as determining factors in how fast a team will complete product development and Ulrich and Eppinger [5] give examples of how these criteria predict many other dimensions of team performance, as well.

#	Criteria
1	There are 10 or fewer members on a team
2	Members volunteer to be on the team
3	Members remain on team from time of conception until product release
4	Members are assigned full-time to the team
5	Members report directly to the team leader
6	Key functions, including at least marketing, design, and manufacturing, rest with the team
7	Members are in conversational distance of each other

Table 2-1: Smith and Reinersten, seven criteria that determine how fast a team will complete the development of a product [14], [5].

The criteria in Table 2-1 are strong indicators of team performance, though they risk development of an exclusive team. People will usually volunteer to work with others with whom they are friendly. If someone happens to volunteer to be on a team whose members do not particularly want them to be on the team, it could hinder performance. The above criteria assume that all team members will fully and equally contribute. In academic settings, particularly with younger students, teams formed based on student preferences often spawn social development more than technical development. Also, some students volunteer for teams comprised of advanced students, because they want to be acknowledged for the work of the team, though their contribution is minimal. Without a framework that compels each team member to fully contribute, often the criteria above weigh less heavily. In particular, unequal member contributions have been observed from primarily homogeneous teams with a disproportionate amount of diverse members (e.g. a team comprised of 3 males and 1 female). Deterministic Design with PREP contributes a framework for normalizing the participation of members of diverse teams, regardless of race, gender, level of preparedness, and/or personality differences. When teaching design, I randomly select the members for each design team and PREP has proven to be helpful in facilitating team member contributions.

When looked at from the standpoint of how this work affects women and minorities, it may appear this process is addressing a social issue. However, when looked at from the standpoint of getting all members of a team to effectively contribute, it becomes clear this it is a design process problem. The book "No Excuses: Closing the Racial Gap in Learning" [18] by Abigail and Stephan Thernstrom cites a multitude of references to work in the area of bridging the racial gap. It is but one of many books on narrowing race related disparities, however it is not the same as what is being proposed here. Social processes and programs are approaches to leveling playing fields (e.g. closing the racial gap). My work is an approach to getting all the players playing (i.e. getting everyone to contribute, gap or no gap). As a child, I was part of programs such as busing, gifted programs, honors classes, etc., which were primarily focused on maximizing student potential by changing the academic environment. My work is focused on maximizing the contributions of team members by changing their development practice. Team members bring various skills/education to the table, but the whole often ends up being less than the sum of the parts, because many teams do not have all of the members fully contributing. I believe this affects the seven criteria proposed by Smith and Reinersten (see Table 2-2). Adding PREP to the criteria outlined by Smith and Reinersten facilitates collaboration and in turn can reduce the time it takes to complete projects. Design process knowledge is independent of domain knowledge; however PREP helps identify the domain knowledge of team members and in effect helps structure teams.

#	Criteria	Counter
1	There are 10 or fewer members on a team	More team members may be necessary if all do not contribute
2	Members volunteer to be on the team	If all are not comfortable with or do not respect each other, certain contributors may be excluded
3	Members remain on team from time of conception until product release	If all members are not fully contributing, substituting with a more connecting member may yield better results
4	Members are assigned full-time to the team	Full-time presence does not necessarily equal full contribution
5	Members report directly to the team leader	Members reporting to the team leader without first reporting to each other may result in trust issues
6	Key functions, including at least marketing, design, and manufacturing, rest with the team	Important to identify the domain knowledge of members and ensure members are responsible for task that interests them
7	Members are in conversational distance of each other	Individual thought is important and it is possible to be too vocal

Table 2-2: Counters to Smith and Rothstein, seven criteria that determine how fast a team will complete the development of a product.

3 DETERMINISTIC DESIGN

3.1 Deterministic Design with PREP

The supposed "scientific method"[1] commonly includes the following steps:

1. Identify a problem
2. Develop a hypothesis
3. Design a controlled experiment
4. Run the experiment and gather data
5. Analyze the data
6. Modify the hypothesis accordingly
7. Repeat the process until it converges

This is similar to many design processes, including Quality Function Deployment (QFD) with its multitude of steps [4]. Perhaps the scientific method is a foundation for most problem solving thought processes. My work presents a design process that stresses the importance of keeping things simple, especially in the initial stages of design/modeling, with an added practice to foster healthy collaboration.

Billy Vaughn Koen[2], in his book "Discussion of the Method, Conducting the Engineer's Approach to Problem Solving" [20], lists dozens of rules of design. While keeping things simple is not generally stated as a design rule, it is implied. Using heuristics to improve designs and/or make decisions implies that design should be simple; it is an approach to simplifying designs, by using available resources to make the best change(s) (i.e. having/using heuristics helps keeps design simple).

Many engineers often fail to observe schedules and other details required for successful on-time completion of projects. This can be resolved by merging qualities of the scientific method with the business focus of risk assessment and countermeasures, and schedules:

- Observe the problem and its physics

1. Scientific Method as summarized by Slocum, A., Graham, M., and Abu-Ibrahim, F., "Teaching Design With A Peer-Review Process" [19]. Some see the design process as being quite different from the scientific process. The scientific process leads to new understanding and the design process leads to new products. However, similar processes can be used to reach different ends.
2. Billy Vaughn Koen believes his engineering heuristics method of problem solving can be used for general problem solving.

- Develop a hypothesis/solution
- Use peer-review to evaluate the hypothesis and later the solutions
- Analyze the proposed solutions, and perform Bench Level Experiments (BLE)
- Study references and appraise solutions to identify the "best one"
- Assess the risks[3]
- Plan countermeasures
- Employ, examine and enhance the idea to alleviate flaws, and resort to countermeasures if falling behind schedule due to profound complexity

The process outlined above is an overview of a deterministic design process to help facilitate orderly and timely completion of design projects. It is not proposed that engineers thinking differently about problem solving will address the numerous business issues faced in industry (e.g. market shift, misallocation of talent, weak program management, hierarchical communication paths, etc.). However, it provides a framework for them to efficiently contribute their talents to the pursuit of corporate prosperity. My experience with the process has overwhelmingly been in academic settings. In corporate use, it may be particularly useful for short term projects, where time may be too limited for an approach such as QFD.

Because this method seeks to minimize unknowns using analysis and identification of possible risks and potential countermeasures, and to map out a solution path and implementation plan, we generally call it Deterministic Design, which we apply with a Peer-Review Evaluation Process (PREP). Table 3-1 captures the process of Deterministic Design with a brief explanation of each step. PREP occurs after each step of development.

3. For more detail than common knowledge, or gut feeling, Failure Mode and Effect Analysis, FMEA [16], or Finite Element Analysis, FEA [17] can be used to assess the risks.

Deterministic Design	
Functional Requirements (FR) - Events/Actions	A list of independent functions that the design is to accomplish.
Design Parameters (DP) - Solutions	Each FR can have several potential DPs. The "best one" ultimately must be selected.
Analysis	Each DP's feasibility should be proven quantitatively, or at least qualitatively.
References	Anything that can help develop the idea, including personal contacts, articles, patents, Internet, etc.
Risks	High, Medium, Low (explain why) development risk assessment for each DP.
Counter-measures	Ideas or plans to mitigate each risk, including use of off-the-shelf known solutions.

Table 3-1: "FRDPARRC" (pronounced "Fred Park") coined by Prof. Alexander Slocum at MIT.

Idea development is a sequence of three stages: Strategies, Concepts and Modules. Each stage essentially requires addressing the issues in Table 3-1: Functional Requirements, Design Parameters, Analysis, References, Risks and Counter-measures. As shown in Figure 3-1, first strategies are determined (overall approaches to solve a problem) and then concepts are developed to implement the strategies. Simultaneous consideration of strategies and concepts allows for the best concept to be chosen: the best strategy is the one that likely achieves the best performance with the most manageable risks. Afterwards, the individual modules of the project are designed. This concept of Deterministic Design, which provides the structure for the three stages of idea development, still leaves a lot of room for the free creative spirit that inspires experimentation and examination.

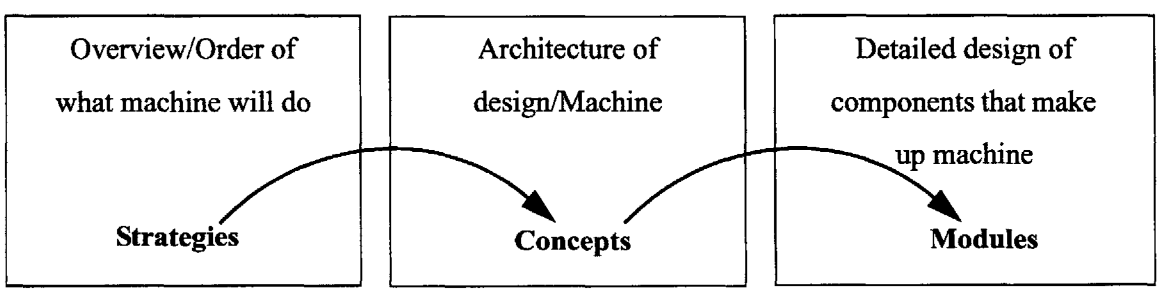


Figure 3-1: Block diagram of the stages of idea development

At each stage of creating (strategy, concept, and modules) a deterministic process occurs and individuals independently create (and write down their ideas), peer-review, and then discuss and select. This crucial process, has helped people (particularly underrepresented minorities, women, and introverts) function as fully contributing members of design teams.

Individual Thought constitutes the first phase during each of the steps of Deterministic Design and more generally the three stages of idea development. During this phase, things are done in leisure to inspire creative thought. Observations are made of what other people have created, the library/web is searched, and the best are taken from different ideas to evolve them into the best two or three ideas. The information in Table 3-1 is updated and Milestone Reports are created for the top ideas, in such a way that any random person can understand the ideas without any unwritten explanation.

During the second phase in developing ideas, a peer-review process is employed, where (N) people circulate their Milestone Reports to the other (N-1) people for comments. A written record is thus also made of who first had the idea, so personality conflicts are more easily avoided. No talking is allowed and written constructive comments are made on each other's papers, until everyone has evaluated everyone else's ideas. This method creates a collective mind, so everyone knows what everyone else has been thinking. It also helps identify the domain knowledge of each team member, specific to the idea being developed.

Discussion/Brainstorming is the third phase, which helps teams solve personal creativity deadlocks and helps to ensure nothing has been overlooked. Initially, everyone voices their suggestions, and then ideas are distilled. If there are unknowns or great risk items, rather than endless discussions, team members are sent off to gather data and run experiments. Every decision must be made based on facts and reason, not emotion or status (i.e. criteria should be measurable and decisions should be the result of analysis).

Collectively, we call these three phases the Peer-Review Evaluation Process, or PREP (see Figure 3-2). It maintains the creativity of individuals and the power of teams, and provides a written record for how ideas evolve.

Figure 3-2: Peer-Review Evaluation Process, PREP

A team must evaluate design alternatives and various methods are well known. The simplest is a linear weighing scheme where the list of ideas (strategies, concepts, or modules) is used as the evaluation parameter[4]. A "weighted selection chart" uses the same basic ideas as a Pugh Chart, but it includes a weighting column for weighting the importance of the design attributes. A compromise is to start with equal weights, and then if convergence is not reached, consider giving priority to some of the attributes. A relative importance weight to each evaluation parameter may be set, and one design is set as the baseline to which all others are compared by setting ones and zeros. Once the "best" design is found by totalling results, students look at other designs that have higher scores for certain criteria and see if those characteristics can be transferred to the "best" design to make it even better. Figure 3-3 is an example of a weighted selection chart with "Criteria 3" determined to be twice as important as the others. "Idea 2" was selected because it had the highest total, but characteristics of "Criteria 2" and "Criteria 4" for "Idea 3" and "Criteria 4" for "Idea 4" are further explored in developing "Idea 2". Again, the prime purpose of the chart is to identify the most promising ideas, and then replace whatever

4. Prof. Stuart Pugh [11] took the approach that these sorts of methods are powerful, but engineers may spend more time creating matrices and evaluating options than they do creating ideas. Pugh's approach was to call for a table, now referred to as a "Pugh Chart".

deficient modules they have with better modules from other ideas. Evaluation of design alternatives is also compatible with QFD and other similar methods.

	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Total
Idea 1	0	0	0	0	0
Idea 2	1	0	1	0	3
Idea 3	0	1	0	1	2
Idea 4	0	-1	0	1	0

Figure 3-3: Weighted Selection Chart with 1 weighted criteria

Many designers and design teams have design reviews before investing large dollar amounts into development. In a way, they already do design with peer-review and may complain about the time they spend in meetings, presumably doing peer-review of progress on a design. However, PREP is not to be used to review progress; it is a development process that ensures that the best approach is always being pursued, and that everyone is fully contributing and taking ownership from the beginning of the project. It is not intended to add time to the design process; in fact, it may reduce time by getting everyone fully involved. It also helps to understand what team members are doing at any time throughout development.

4 DESIGN COURSES AND PROGRAMS

A nuber of MIT design courses and programs were the basis of validating the method of teaching product development by Deterministic Design. Descriptive research was applied to develop the theory and direct observation, interviews and questionnaires were used to gather data. This chapter describes the design courses and how the method was applied in each course/program and what was learned.

4.1 Teaching Deterministic Design with PREP

For six years I instructed and monitored students using Deterministic Design with PREP to develop products and engineering design projects. Students ranged in level from high school freshman to college seniors. I noted differences in how each level of designer was able to manage each of the three phases of PREP: 1) Individual Thought, 2) Written Peer-Review, and 3) Group Discussion and Idea Selection. I therefore have learned to alter the process for each level of designer to match their preparedness. Consequently, I set the personal goal to optimize education at each level.

Of the numerous design processes in practice (e.g. those listed in 1 INTRODUCTION) Deterministic Design with PREP is a comparably attractive process for many fundamental reasons. This innovative process encompasses key characteristics from a number of processes (Precision Machine Design, QFD/TQD, Axiomatic Design, Method 635, and Delphi Method) and can be presented and executed without extensive training. In practice, Deterministic Design with PREP has produced significant results. I used it mainly as a teaching tool to introduce students to design as a process. As designers become more advanced and are introduced to more processes, Deterministic Design with PREP will have prepared them for speedy adaptation. Also, PREP ensures that all team members have the opportunity to contribute equally throughout development, making it an attractive practice as women, underrepresented minorities, introverts, and through technological advancements, the disabled more frequently join design teams.

In design teams, I evaluated the percentage contribution of each teammate to the outcome of the development (design sophistication in terms of proper application of machine elements and overall performance in design competitions - example: Figure 4-1). The team with the largest participation throughout the design process developed the most sophisticated design and placed highest in competition; conversely, the team with the smallest participation throughout the design process developed the least sophisticated design and placed lowest in the competition. In addition, for individual designers I evaluated the frequency of peer-review versus time to complete and design improvement; when reviewers had a stake in the project, peer-review almost always decreased completion time and improved designs for most designers; the thoroughness of peer-review decreased the less stake reviewers had in development.

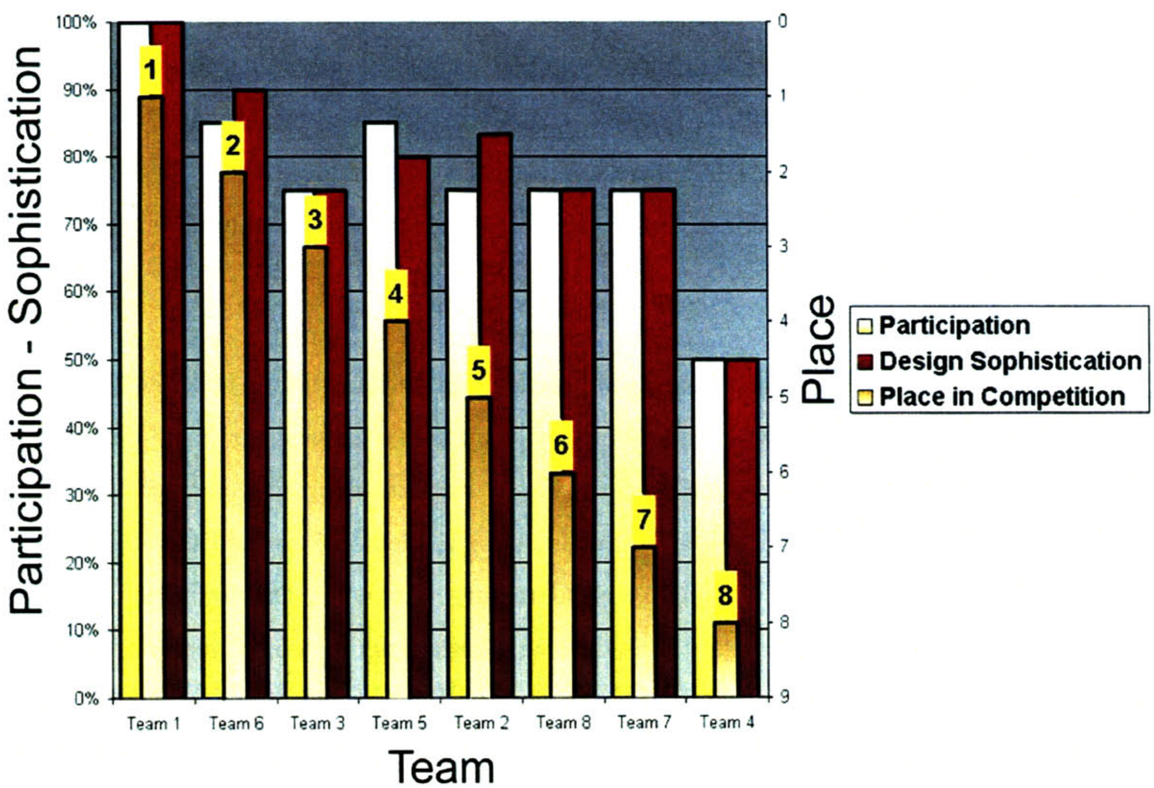


Figure 4-1: MIT special program MITES - 2005 Engineering Design course results

Figure 4-1 displays the results from the 2005 MITES program engineering design course. Upon completion of the course, students were given questionnaires and asked to report to what extent each team member contributed. I along with the teaching assistants for the course judged the sophistication of each team's design. Each member of Team 1 fully contributed to the development of their team's machine, while effectively only half of the members of Team 4 fully contributed to the development of their team's machine. Design sophistication (measured in terms of design for objective, proper use of machine elements, properly constrained components, and machining) was determined by the staff to be greatest for Team 1 and least for Team 4. All other teams had over 75% contribution and close to equal design sophistication.

4.1.1 Evaluating Designers

When evaluating designers, I divided the users of Deterministic Design into four levels based on their preparedness to apply the process: 1) Young Designers - High School Freshmen and Sophomore Students, 2) Adolescent Designers - High School Rising Seniors and College Freshmen, 3) Intermediate Designers - College Rising Sophomores through Seniors, 4) Experienced Designers - Graduate Students and Practicing Engineers. Experienced designers were not studied as meticulously as other levels, as this was more of an engineering education study. In the sections that follow, I will discuss how Deterministic Design was applied by designers at each level and how I altered the presentation of the process accordingly.

4.1.2 Young Designers - High School Freshmen and Sophomore Students

Young designers have yet to learn enough math and science to solve complex design problems. In my experience with young designers (in mostly those from underprivileged school districts), they are unprepared to independently carry out the stages of deterministic design, so individual thought contributions are at a minimum. Students are not pushed to research how to apply fundamentals they have yet to learn; instead, examples and questioning are used to guide independent development. I noticed that during the peer-review phase, young designers are stimulated by the ideas of their teammates and tend to further produce ideas, more so than review those of their teammates. The process is modified as follows to accommodate this practice[1]: 1) Individual Thought, 2) Peer-Review, 3) Individual Thought, 4) Peer-Review, 5) Group Discussion and Weighted Selection (Figure 4-2). In detail, the process is carried out as follows: 1) instructor gives examples to students (take-apart exercises, mechanism images, demonstrations, etc.) before

1. This use of the process is encouraged for young designers. The process is also often used in this manner with older and more experienced designers. It is of utmost importance to resolve all issues before proceeding to the next stage. PREP should be repeated as many times as needed between design stages to reach satisfaction and meet requirements (customer and functional) before moving forward.

having them individually brainstorm ideas, 2) students peer-review work and are stimulated by the ideas of team mates, and 3) PREP continues as normal.

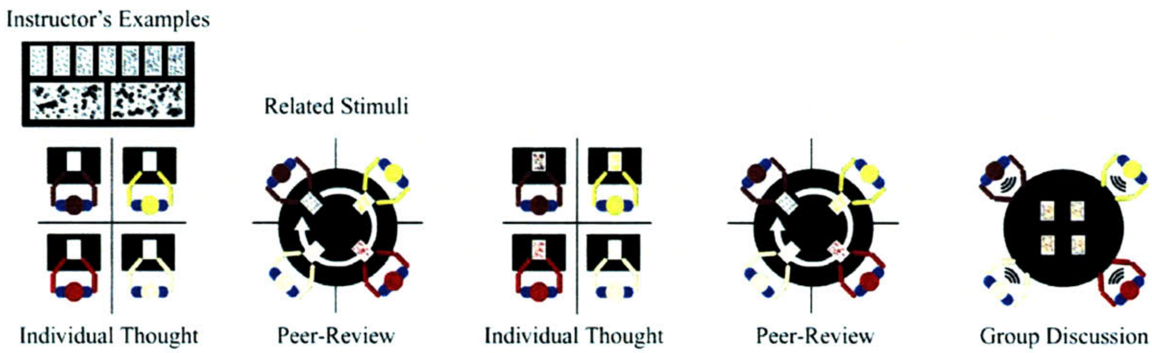


Figure 4-2: Peer-Review Evaluation Process (PREP) modified for youth designers

I found that young designers understand weighted selection, but need guidance in carrying out the process. They are able to determine many of the important factors, though because they lack experience in modeling and approximations, they have difficulty evaluating ideas against a baseline.

Based on these findings my foci when instructing young designers are to 1) introduce them to independently carrying out the stages of Deterministic Design, 2) introduce them to using related stimuli[2] (first round of peer-review), 3) develop their peer-review skills (second round of peer-review), and 4) help them gain experience at modeling and approximating (weighted selection).

This approach to teaching young designers is similar to the approach used in many martial arts dojos, where the instructor sets the pace to push the middle of the class, while the more advanced students improve their skills by assisting the least advanced. At the outset of the course, a diagnostic exam or background evaluation is completed to find mean level. Lesson plans are

2. Ulrich, K.T., Eppinger, S.D., Product Design and Development, McGraw-Hill Higher Education, 2000 p.121; example of related stimuli - each individual in a group session generates a list of ideas (working alone) and then passes the list to his or her neighbor.

prepared such that the mid-range of the class is challenged and the most advanced students (or the ones that catch on quickest) help bring the least advanced students up to speed. Mid-range students, who are encouraged by instructor, along with the least advanced students are challenged by the material, while the most advanced students solidify their grasp of the fundamentals through instructing less advanced students.

4.1.3 Adolescent Designers - High School Seniors and College Freshmen

Adolescent designers have learned enough math (algebra, geometry, and trigonometry) and physical science to solve complex design problems, but in most cases have not been presented such a challenge. I found they are able to independently carry out the stages of deterministic design, and I push them to apply fundamentals learned in math and science courses to design engineering. While some are naturally more critical than others, in my experience generally they have had no formal experience reviewing the work of others. They have been trained to think competitively, which in many cases conditions them to not give positive feedback and to be resistant to receiving it. During the peer-review phase, adolescent designers initially offer comments such as "good", "don't understand", "agreed", etc., not taking ownership of the work of their peers. I condition them to internalize the work of their peers, by reviewing it as if it was their own and they are checking for oversights they personally made along the way. I find the approach leads to more introspective feedback helping to further develop, and results in less phrases that lack detail, such as "thumbs up/thumbs down". Stimulated by the ideas of their teammates they begin thinking of ways to synthesize ideas, while conducting peer-review. During discussion, they explain their comments and share their thoughts for moving forward. They are able to determine many of the criteria, but some (mainly rising seniors) need assistance with modeling and approximation; for the criteria, they are able to compare the ideas against a baseline. Through weighted selection they pinpoint the best qualities of each idea and are often able to synthesize many of the top qualities into one, or two designs.

Based on these findings, my foci when instructing adolescent designers are 1) fostering their conception skills working as individuals[3], 2) expanding their self-interest to team-interest in the critical thinking to improve ideas, 3) selecting criteria that are measurable and based strongly on the requirements of their design, and 4) improving benchmarking skills needed to complete weighted selection analysis.

Adolescent designers are more attentive to lectures than young designers and very eager to apply newly learned mechanisms. In addition, since they don't have much freedom in choosing courses or instructors, they do not yet feel complete ownership of their education and, with the exception of a small percentage, tend to follow directions without question; introducing design skills at this age not only avoids such barriers, but helps develop these questioning skills that are useful in college. To gage the effectiveness of their use of Deterministic Design with PREP, surveys were given to the students.

Upon review of the ideas of adolescent designers, I offer a gallery of mechanisms for them to research based on characteristics of their initial ideas. Students use the suggestions to help them conceive more ideas before peer-reviewing with their teammates. I also hold semi-weekly to weekly design reviews with design teams. In addition, examples of how to model and approximate are presented regularly throughout the courses.

4.1.4 Intermediate Designers - College Rising Sophomores through Seniors

Intermediate designers have the math and science backgrounds needed to solve complex design problems, but have varying backgrounds in terms of teamwork experience. Most work very well independently and can conduct the stages of deterministic design, but often initially fail to see the value in following the process. In fact, many will not use the process, unless it is made a requirement by an instructor. Those who do not take to the process say it is because they do not have time to work on their projects outside of lab; without fail, they quickly find themselves behind those who do follow the process. However, through interaction with the students I noticed that it is not a matter of time, but willingness to give and accept feedback. Students who are most open to giving and receiving feedback take to it and gain the most from the process. Students who are unwilling to give and/or accept feedback offer little, if any, peer-review and often blame the process as having been a distraction that kept them from doing as well as they should have. From

3. Two approaches are 1) a derivation of the Gallery Method - students are encouraged to review concepts that perform functions similar to their requirements and 2) use of unrelated stimuli - students observe random objects and brainstorm ways they can be used, or modified, to meet their functional requirements; Ulrich, K.T., Eppinger, S.D., Product Design and Development, McGraw-Hill Higher Education, 2000 pp.121-122.

this and my work with younger students, I see the value in adapting students to give and receive constructive feedback early in their academic lives.

Based on these findings, my foci when instructing intermediate designers are 1) stressing the importance of scheduling milestones and proper planning to meet them, 2) conducting question and answer, or student grading exercises to open them up to giving and receiving feedback, and 3) assigning an introductory project/exercise to demonstrate the value of Deterministic Design with PREP.

Intermediate designers are capable of conducting research to get an understanding of how to apply principles, or use mechanisms. Small class sizes (less than 30), where students can question instructors and peers, are more effective than lecturing to large groups. Semi-weekly to weekly design team meeting with an expert/instructor is a productive approach to managing workflow.

4.1.5 Experienced Designers

Experienced designers generally have a process they follow. They can function as individuals, or as part of a team. In team environments, they often prefer to divide work and loosely collaborate (i.e. meet regularly to review each others' progress). Experienced designers I introduced to Deterministic Design with PREP agree it is a sound process, though having experience with project planning and peer-review, see it as what they already do. However, some prefer to brainstorm in group settings, instead of individual thought, peer-review and then discussion. With experienced designers, all of whom have a stake in every aspect of the design and respect their fellow team members, the results of idea generation are virtually indistinguishable. If all team members do not have a stake in every aspect of the design, or do not respect their fellow team members, development without individual thought - followed by peer-review - followed by group discussion problems may arise, such as incompatibility when merging developments. Women, underrepresented minorities, introverts, and the disabled have reported feeling neglected by design teams and have become withdrawn as a result. The three phases of PREP provide a structure that protects team members from being neglected. However, just as with intermediate designers, without the requirement of superiors, design teams unaccustomed to Deterministic Design with PREP are not likely to use the process. It may be challenging to convince experienced designers to use Deterministic Design with PREP, without the demand of a project manager, or an incentives program. However, project managers and a good number of educators with whom I have shared the process express interest in adopting it.

4.1.6 Teaching Findings

At each level, students that used Deterministic Design with PREP worked well in teams. There was healthy communication between team members and disagreements were easily resolved through peer-review and weighted selection. The section that follows will detail how Deterministic Design with PREP was used in specific design courses and programs. Student response to use of the process is also included.

4.2 Design Courses and Programs

Course	Years Taught	# of students	Age Range
SEED Academy - Mechanical & Civil Engineering	3 years, 2004 - 2006	24 - 30	High School Freshman - Sophomore
MITES - Engineering Design	3 years, 2003 - 2005	32 - 40	High School Rising Senior
2.971: Second Summer Program - Product Design	6 years, 2001 - 2006	10 - 42 26 average	College Freshman
2.007: Design and Manufacturing I - Machine Design	2 years, 2003-2004	10 - 16	College Sophomore
2.993: Pathways to Peace - Engineered Artwork	1 year, 2002	7	College
SP2H1: Poetry in Progress - Creative Writing	2 years, 2005 - 2006	7 - 8	College
NASA RISE - Engineered Artwork and Engineering Design	2 years, 2002 - 2003	6 - 9	College

Table 4-1: Course map of design courses and programs taught using Deterministic Design with PREP

In teaching Deterministic Design with PREP and monitoring projects completed using the process, much has been learned about designers at different stages of development. While young and adolescent designers individually may not be ready to apply the process in its entirety, many design practices (such as related stimuli, unrelated stimuli and the gallery method) can help them develop thought processes common to design engineers. Formal design curriculums were implemented in courses for students ranging from high school freshmen to college seniors. Also there was collaboration with Universidad de Antioquia (Antioquia, Colombia). Deterministic Design with PREP was demonstrated to a professor who was a visiting scholar of the MITES Program for a summer. The process was in-turn taught to professors and students at Universidad de Antioquia. There has also been collaboration with faculty at Universidad de Castilla-la Mancha (Ciudad Real, Spain) and Deterministic Design with PREP is being implemented in their design curriculum. Both schools are in early stages of adoption.

Through MIT special program SEED Academy, Deterministic Design with PREP was introduced to high school freshmen studying mechanical engineering and their understanding was reinforced as sophomores studying civil engineering. The freshmen used the process to design and build battery operated remote control cars and consumer products. The sophomores designed and built beam, arch and suspension bridges. Having learned the process as freshmen, they showed much improvement in applying fundamentals learned in lecture to their designs. Their knowing the process not only allowed me more time in lecture to focus on teaching civil engineering principles, but it also let them know how they would use what they were learning in practice.

For three summers as part of the MIT special program MITES, Deterministic Design with PREP was taught to high school rising seniors studying engineering design. During the first summer, the students had five weeks to design and build machines to operate on the MIT course 2.007 competition table. The 2.007 students had three months to design and build their machines, working as individuals (some using Deterministic Design with PREP) and the MITES students had five weeks working as teams of four using Deterministic Design with PREP; the winning machine from the MITES competition outscored the winning machine from the 2.007 competition. The next summer, the MITES students were given an additional robotics challenge. Not only did they build a machine to navigate the 2.007 competition table, but they also built autonomous vehicles to operate on a track positioned above the table. During the third summer, the competition table for the course was developed using Deterministic Design with PREP by a design team consisting of the teaching assistants, a visiting scholar, and myself. The student teams designed and built one completely autonomous vehicle and one semi-autonomous vehicle to compete on the table. The students kept their development in on-line design notebooks, which they updated daily. In addition to engineering design, they also studied calculus, physics, biochemistry and humanities. A great majority of the students, many of whom prior to the course felt it was unnecessary to learn a design process, remarked that without having learned a design process it would have been impossible for them to design and build comparable machines and robots in five weeks.

The Second Summer Program (MIT course 2.971), a three week design seminar during January (Independent Activities Period), prepares MIT freshmen for project work at summer internships arranged through the program. The curriculum consists of one lecture to teach students Deterministic Design with PREP and semi-weekly/weekly design reviews with the instructor. The students are given a design objective and machine shop training. They meet everyday with their team members and teaching assistants for peer-review and later machining, building, testing and refining. As a finale to the program, the students present their work to their peers and a panel of judges. Feedback from the MIT Office of Minority Education (OME) is that the percentage of minority students that later in their academic career must come before the committee on Academic Performance has dropped from above 10% to as low as 2%. In addition, the OME has stated that companies offering summer internships report that in team settings the rising sophomore students having learned Deterministic Design with PREP function on the level of a graduate engineer or higher.

In the NASA RISE summer program, college rising sophomores through seniors were led in the development of mosaic tiles designed using SolidWorks and manufactured using the Waterjet abrasive cutting machine; they were also led in the design and development of Rube Goldberg projects[4] - "10 steps to stop an alarm clock". For the MIT course 2.007 (Introduction to Design and Manufacturing), I was the lab instructor for 11 students, 3 of whom made it to the final 16 and 2 to the final 8 of the 118 students in the final design competition; the highest place

4. Rube Goldberg projects, named after the engineer/cartoonist, are projects that require a complex chain reaction execution of simple tasks.

for a student from my section was 2nd. The students in my section developed their machines using Deterministic Design with PREP. I believe their notable performance was in part due to their use of Deterministic Design with PREP. They were among the first in the course to have machines ready for testing and their final models were nearly identical to their first models. Extensive testing time and familiarity with their machines' functions helped them perform well in the final competition. I believe the advantages were due in part to their use of Deterministic Design with PREP.

4.2.1 Saturday Engineering Enrichment and Discovery (SEED Academy)

Saturday Engineering Enrichment and Discovery is an MIT program for students from a number of Boston, Cambridge, and Lawrence, Massachusetts high schools. It was founded as a program to increase the low number of underprivileged students from the greater Boston area admitted to programs like MITES and top tier colleges. It is a three and one-half year program and students are admitted during the second half of their freshman year. The first class graduated in 2005.

The freshman mechanical engineering and sophomore civil engineering course curriculums are centered around projects the students complete using Deterministic Design with PREP. At such a young age, these students are generally use to being told by authority figures, what is important and learning just that. In my opinion, practicing Deterministic Design with PREP helps the students become active learners; they ask and answer more questions and develop a sense of ownership in their education. Students enter the program ready to learn whatever they are assigned, but over time I have noticed students begin to propose what they are interested in learning. In reviewing the work of others, they learn to think in ways in which they have not been challenged before. I believe this type of thinking will prepare them for research and careers in science and engineering.

Over three years, the amount of design liberty entrusted to the students varied from close to no creative freedom to complete creative freedom. I concluded that the most appropriate approach to balancing learning and design liberty is to assign everyone the same project and allow them the freedom to develop the modules in ways they see best. For example, the mechanical engineering students were assigned the task of designing and building remote control cars. All teams were given the same parts to build each module (a plywood base, cordless hand drills, wooden and steel shafts, tie straps, velcro, wire and switches), how they built each module using specific parts was up to them. Differences in designs were subtle, such as the number of wheels used, shape of car, and mounting of motors and batteries and switches. The civil engineering students were assigned the task of designing and building bridges (arc, truss, or suspension). All teams built either arc or truss bridges, so as a follow-up, students were given designs for and assigned the task of building suspension bridges (a type, or 1 cable).

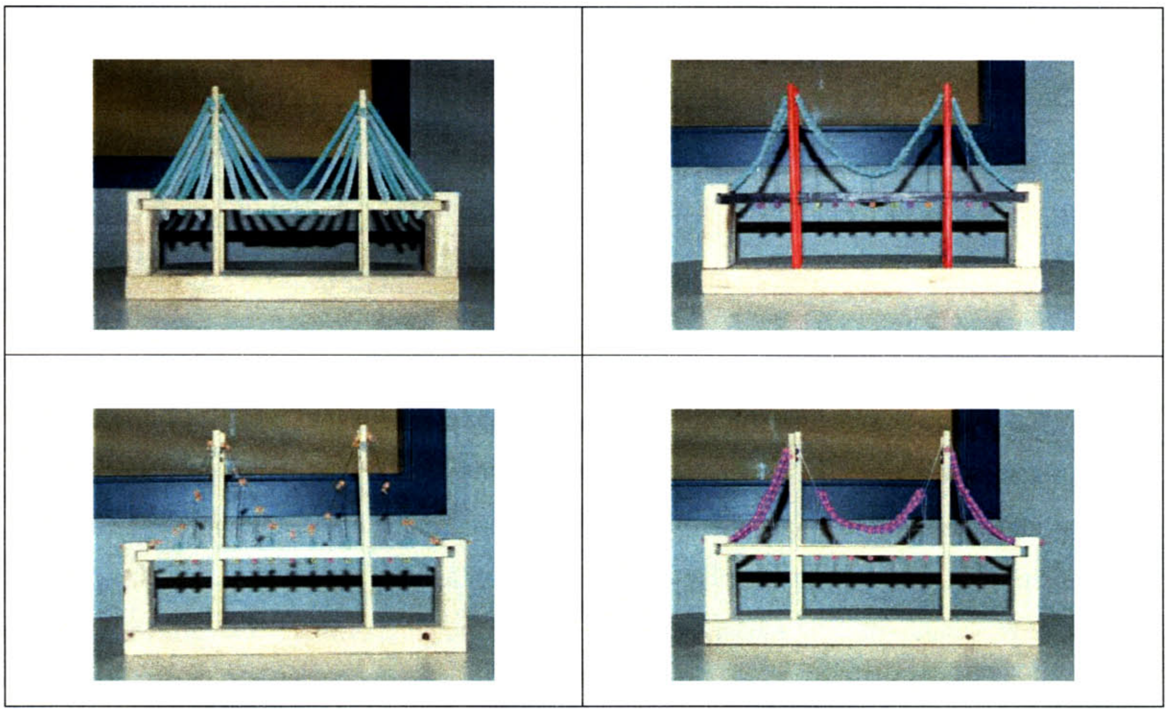


Figure 4-3: SEED Academy 10th Grade Civil Engineering Suspension Bridges: (1) a type and (3) 1 cable

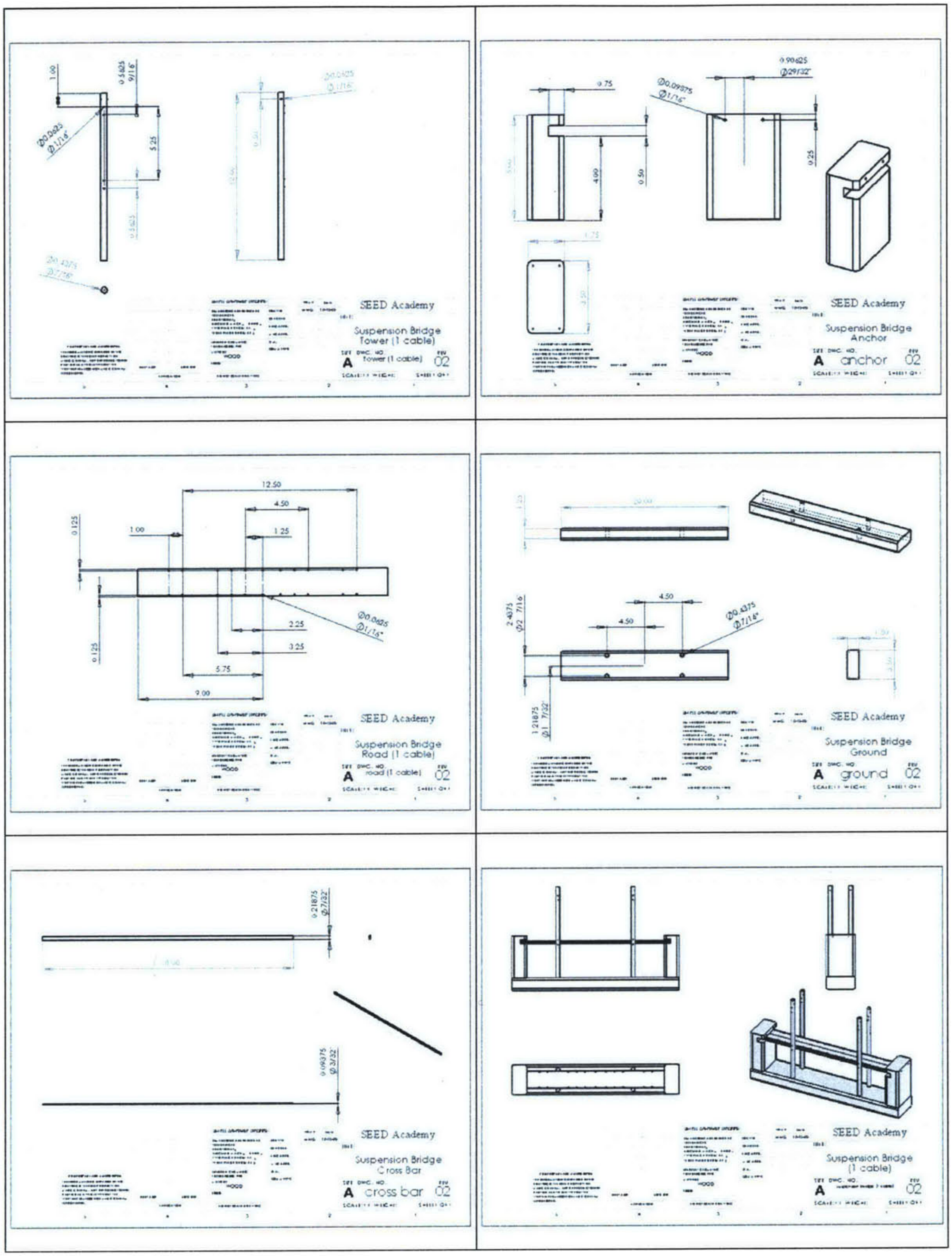


Figure 4-4: SEED Academy 10th Grade Civil Engineering drawings for suspension bridge

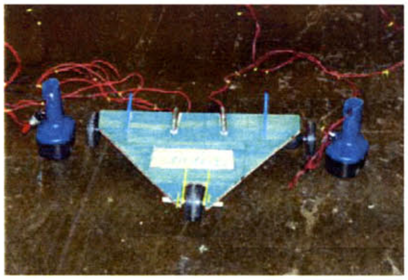
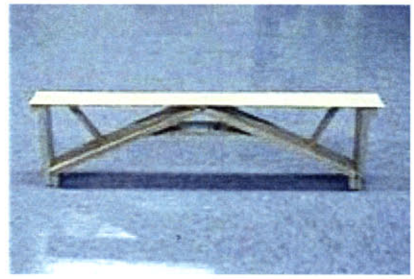
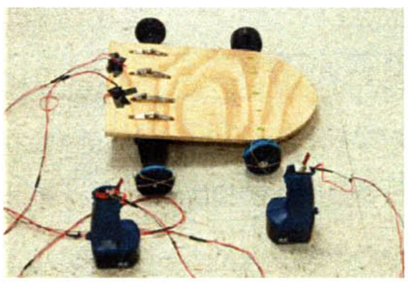
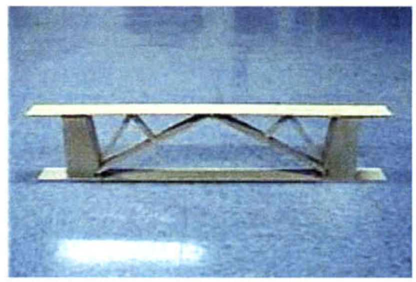
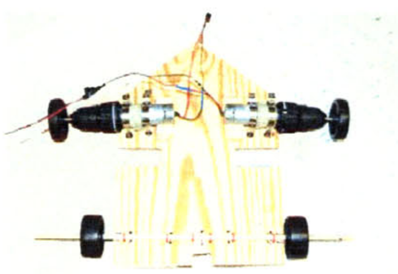
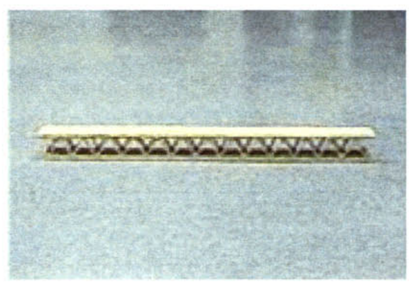
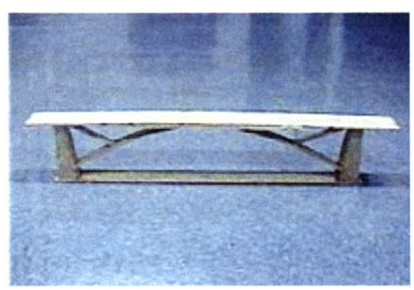
9th Grade Mechanical Engineering	10th Grade Civil Engineering
	
	
	
	

Figure 4-5: Remote cars and bridges designed and built by SEED Academy students

4.2.2 Minority Introduction To Engineering and Science (MITES)

Minority Introduction to Engineering, Entrepreneurship and Science[5] is a rigorous six-week summer residential program for rising high school seniors who are interested in studying and exploring careers in science, engineering and entrepreneurship. MITES began as a program for minority students, though while affirmative action in college admissions was being tried in the Supreme Court in 2003, it was expanded to an all-inclusive program and now admits a more diverse group of students.

MITES students are very capable of designing deterministically and teams are given complete design freedom. They are assigned the task of designing semiautonomous robots to overcome obstacles on a competition table. To challenge teams to work with other teams, scoring for competing teams is equal to the combined score of the two teams divided by two. The team with the overall highest score at the conclusion of all rounds is the winner of the competition (see the rules for the competition below). Instructors and TAs use Deterministic Design with PREP to design the competition table, develop the rules, and evaluate the students. The students use Deterministic Design with PREP to design and build their machines and evaluate the performance of their peers.

Rules for the MITES Engineering Design Competition

The MITES Design Competition will take place in an area known as "The Arena". There will be eight teams engaged in friendly competition, two teams at a time. In this case, friendly competition means that teams will not benefit by offending their "opponent". Scores for each round will be the combined score of the two "competing" teams divided by two. Competition will be round robin and a team's total score will be the combined score of all their scores from previous rounds.

Competition Scoring:

"The Arena" has a number of scoring locations:

$$\text{Round Score} = \frac{TeamX_{Total} + TeamY_{Total}}{2}$$

$$TeamX(\text{Final Score}) = TeamX_{Round1} + TeamX_{Round2} + \ldots + TeamX_{Round(n-1)} + TeamX_{Round(n)}$$

1) Remote Control Maze

5. http://web.mit.edu/mites/www/about/overview.html

2) Autonomous Maze

3) Ball Holes

4) Bar

5) Mind Field

At the start of each round, a team will be positioned on each side of the Start Zone. Each team will be required to navigate the maze (Remote Control Maze or Autonomous Maze) on their side of the Start Zone. Prior to entering the start zone, it is necessary to release a Lego Mindstorm™ robot onto the Mind Field to locate hidden minds. Upon exiting the mazes, balls will be released into the Ball Pool. Points can be scored by transferring balls from the Ball Pool into the Holes on the incline in front of the Ball Pool. Points can also be scored by lifting the Bar and repositioning it on elevated rungs on the incline in front of the Mind Field.

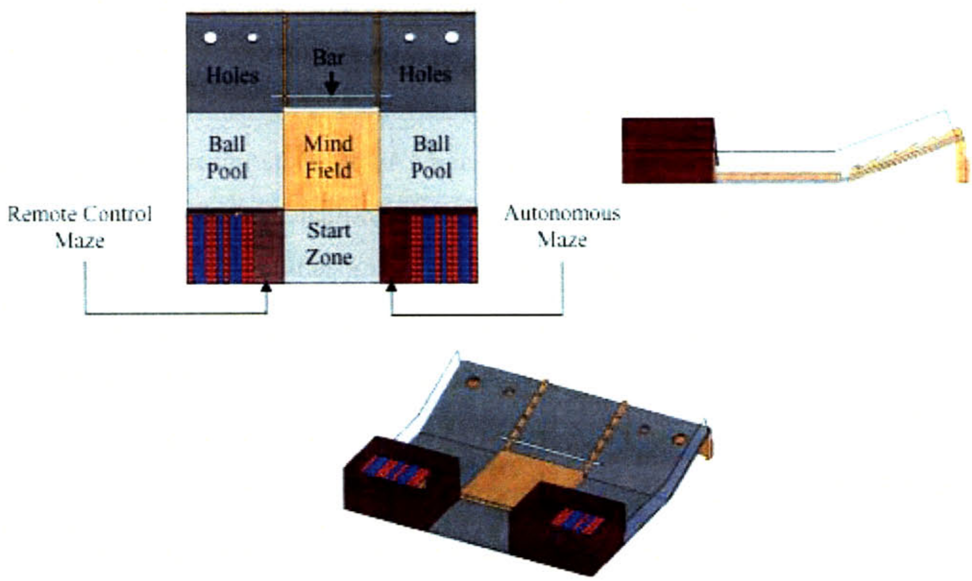


Figure 4-6: 2005 MITES Engineering Design Semi-Autonomous Robot Competition Table

Total Round Score:

Total Remote Control = [(10 + 10 x #Remote Control) + (2 x #small holes + 3 x #big holes + 3 x #bar rungs)] x (1 + #Mindstorm)

Total Autonomous = [(10 + 20 x #Autonomous) + (2 x #small holes + 3 x #big holes + 3 x #bar rungs)] x (1 + #Mindstorm)

At the outset of the summer, the students were given drawings of the competition table, along with the rules for the competition. After a week of introductory lectures, they were given kits to begin the designing and building of their semi-autonomous robots. Throughout the summer, the students kept design notebooks as a record of the work they completed each day. Below are notes from a Student's[6] Design Notebook, demonstrating the use of Deterministic Design with PREP in the MITES program.

July 5, 2005

Project Notes

To begin my strategy development, I first laid out all of the battlefield's required tasks and made some notes of ideas on how to complete them:

~ 1a) Tap Switch >> requires efficient wall finding and rather precisely planned turning radii as to not lose time in maze

~ 1b) Follow Line >> need good sensoring - position of sensor must be taken into account and there should be as little traction on the frontal wheels as possible as to have less wobbling and achieve a straighter travelling path

~ 2) Release Mindstorm Robots >> precision stopping and timing should be taken into account - test trials for stopping distance and sensitivity/reaction rate (time it takes robot to stop and unload Mindstorm robots)

~ 3) Balls into Holes:

"LARGE >> less accuracy - attempt to round up balls onto one side and let balls fall into hole eventually

"SMALL >> more accuracy - maybe send off individual mini-robot to collect stray balls to place into hole

~ 4) Raise the Bar >> (4 notches max) - arms needed (w/ grips as to not let bar slip out of place and evenly placed along the bar as to provide full distribution of the weight of the bar and not let it get knocked off balance) + travel precision (test trials needed to time and average the number of steps needed to reach the fourth notch [one less is better than one more as to not run off the course])

STRATEGIES:

1.Put focus on completion of the Mindfield as to double score - all other areas should be completed decently but not to the greatest precision as to allow time for the completion of the Mindfield - the unloading of the Mindstorm robots should to carefully planned and executed - multiple trials and an average should be draw to produce the best set of working data to act with

2.Management of ball collection should be placed as top priority - maybe the robot can extend two long barriers opened widely and connected at a vertex to round up and aim balls accordingly into the area of the larger hole - stray balls will be dealt with afterwards and less time should be spent on other areas on the battlefield as to leave time for ball collection

3.For my third strategy, I propose that all the aspects of the course should be completed with 70% precision & accuracy and 30% speed, ideally, as to make sure each part of the arena is completed and emphasis is then distributed evenly

6. Notes from the design notebook of 2005 MITES student, Mindy Eng.

During our PREP, we each wrote down our three strategies individually with no collaboration. Afterwards, we passed our idea sheets around the table and jotted down comments on each idea sheet. When this was completed, we discussed what we thought were impressive ideas that should be considered for implementation into the final project. We also discussed problems in good ideas and built upon them by suggesting improvements. This was what we compiled after our discussion and PREP session:

PLAUSIBLE ATTRIBUTES:

1.rounded, extended, frontal bumper rather than simply a flat frontal bumper

2.placement of a frontal light sensor to provide for best steering

3.low friction frontal wheels to provide for easy direction change and little wobbling

4.larger backing up distance and small radius compromise during wall searching period after bumpers are hit

5.timing, multiple trials and precision for stopping and unloading Mindstorm robot

6.rectractable V formation frontal barriers to collect, isolate and maneuver balls to larger hole

7.(if possible) send Mindstorm robot to collect stray balls and bring to smaller hole after activating all Minds

8.two evenly spaced with C-cupped hands arms which can extend from robot - hands should have some type of grip as to not drop the bar

9.extra emphasis on timing for bar as to not bring bar over and off the battlefield and to gain as many points possible

We anticipate the following for our scores:

[10 + (1 autonomous maze x 20)] + [(7balls x 2 trips) x 2 per ball in hole] + (7 rungs raised x 2) = 72 (144 w/ mines)

[10 + (1 r/c maze x 10)] + [(7balls x 2 trips) x 2 per ball in hole] + (7 rungs raised x 2) = 62 (124 w/ mines)

The following is our weighted selection chart - we placed Jennifer's strategy as our scale base:

	Total	Maze x 3	Balls x 3	Mind Field x 3	Bar x 2
Jennifer	0	0	0	0	0
Alicia	-6	-1	-1	-1	-1
Mindy	-8	-1	-1	-1	0
Luis	2	0	0	1	0

Figure 4-7: Strategies Weighted Selection Chart from a MITES student's engineering design notebook.

July 8, 2005

Project Notes

Upon planning to develop my concept cars, I first listed out the tasks we needed to complete for the battlefield. The following are my five proposed concept designs in orthographic projection:

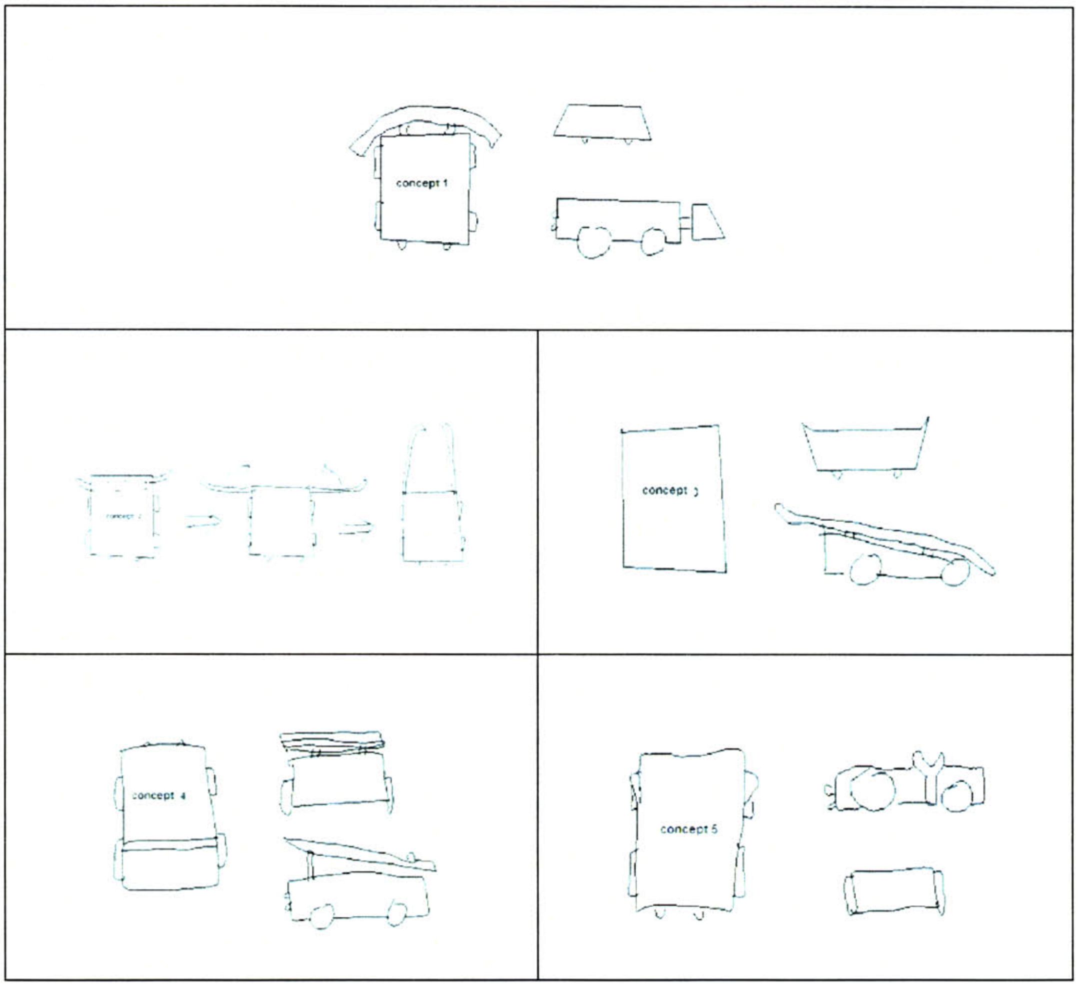


Figure 4-8: Five Concepts from a MITES student's engineering design notebook.

CONCEPT 1:

To complete the maze, we must either complete the autonomous or RC maze. In terms of the autonomous maze, I decided to develop a way to open the flip-door more easily in case our robot does not have enough power to push the door and also to help guide the door off the robot so the door does not knock off certain parts of our robot. To do this, I proposed a static bumper in front of the vehicle that is extended, rounded and slanted at an angle as to protect the robot and let the door slide off the bumper. Also, the bumper can help to keeps balls from hitting fragile parts of the front of the robot.

CONCEPT 2:

To collect the balls, I proposed a technique where the collecting arms can be extended from inside the robot and outwards horizontally as to not take up the space arms attached to the side would in its range of motion. After being extended from the robot, the arm will be able to open and close so that it can round up balls. Its edges are rounded so that balls do not roll out of its grasp as it may be the case if the arms were simply straight. The length of these arms need to be adjusted to the size of the board, the area it needs to span and the amount of space it will take on the robot in accordance to the other accessories the robot might have.

CONCEPT 3:

Since there will be two Mindstorm robots on the Mindfield as one time, I proposed a ramp that would cover our Mindstorm robot so that in case there is a head on collision, the other Mindstorm robot can just run on top of ours. At first I thought that we could also flip over the other teams vehicle but I concluded that a flipped over vehicle would take up space on the arena. Also, if we approach the other teams Mindstorm vehicle sideways, we might be able to push their robot aside with our extended ramp.

CONCEPT 4:

Since we must send off our Mindstorm robot some time during our course, we decided that it would be best to send if off at the start of the contest rather than dragging the Mindstorm robot through the maze and then up the incline. To do this, I proposed a slanted ramp with a stopper that the Mindstorm robot could rest on until the course begins. At the beginning of the course, it would run off the ramp and onto the Mindfield. The head of the ramp would be slightly higher than the height of the Mindfield so the Mindstorm robot can run off smoothly. Not only does this ramp allow the Mindstorm vehicle to begin its mission quickly, the ramp also protects the contents of the robot under it and its slantedness further guides the path of the flip door as to allow an easy exit of the autonomous maze.

CONCEPT 5:

To raise the bar, I proposed vertically retractable arms since the bar is suspended in vertical depressions. With these arms placed at the sides, we can have the choice of either raising the bar on one side or through the center of the course. Once the arm is under the bar, it will extend upwards and hold onto the bar. Grips will be placed on the arm so that the bar does not slip off too easily. Once extended, the robot can move up the incline to raise the bar. At the designated location, the robot can stop and the arm will be retracted back to its original position and lower the bar.

The following is our weighted selection chart for our concept designs. In this chart, we used Alicia as our base scale for comparison:

	Total	Maze x 3	Balls x 3	Mind Field x 2	Bar x 2
Alicia	0	0	0	0	0
Jennifer	1	0	1	0	-1
Luis	-10	-1	-1	-1	-1
Mindy	5	0	1	0	1

Figure 4-9: Concepts Weighted Selection Chart from a MITES student's engineering design notebook.

The text below demonstrates how instructors and TAs use PREP for evaluating students upon completion of the course. Students were evaluated in eight categories, which were the criteria they were informed would be used to determine their grades. The criteria were: 1) Design Notebook, 2) Machining, 3) Robotics, 4) Group Participation, 5) Class Participation, 6) Slope (improvement), 7) Shop Hours, and 8) Risk Taking. Thirty-three students were enrolled in the course detailed below. Spreadsheets were developed to compile the average scores for all evaluators. Using this process, one instructor and four TAs were able to complete the evaluations[7] for all students in under 3.5 hours.

Evaluating Students Using PREP

Please rate students for each category using the point system below. The average of scores (from Instructors & TAs) in each category will be used to write each student's final evaluation.

1 - Poor

2 - Below Average

3 - Average

4 - Above Average

5 - Superb

It should take about 50 minutes for each of us to complete the charts.

33 students x 8 categories x 10 sec/category = 44 minutes

7. Evaluations were form letters detailing student performance for the purpose of feedback and program records. Evaluations were not to be used as reference letters for students.

After we have all rated the students in each category we can divide the students and write about 5-6 evaluations each and review/edit each others evaluations to finalize the evaluations for each student.

It should take about 60 - 70 minutes for each of us to write our individual evaluations.

5(6) evaluations x 10 minutes/evaluation = 50 - 60 minutes

It should about 1 hour and 39 minutes maximum for us to review/edit evaluations.

33 evaluations x 3 minutes/evaluation = 99 minutes

Total time: 3.38 hours each

The evaluations will be written using the template below. However, we will not write evaluations until we have come to consensus on the performance of the students. If you have additional comments about the students, please note them.

The goal of the Engineering Design course is to introduce the students to a Deterministic Design process practiced at MIT in individual and team based project work. They are introduced to concepts like peer reviewing, machining, programming (using Machine Science™ kits), real world Physics, feedback control and project planning. Starting with a box of building materials (e.g. aluminum, wood, plastic, springs, electric motors) and Lego Mindstorms™, the students' challenge is to design and build a mechanical vehicle that operates by remote control and autonomously, and a Lego Mindstorms™ robot that to compete in a space referred to as "The Arena", which has numerous obstacles enroute to the end goal of "raising the bar", this year's MITE2S theme.

"*Student's name*" entered the Engineering Design course with "*insert value*" interest in the subject (*or similar opening sentence*). His/Her design notebook was (*score*). His/Her machining and assembly was (*score*) and robot programming and building was (*score*). His/Her group participation was (*score*) and class participation was (*score*). His/Her overall knowledge of the course material was a(n) (*score*) increase. He/She spent (*score*) hours in shop outside of class time. He/She was a(n) (*score*) risk taker. Overall, "*student's name*" was "*insert comment*" to have in class (*or a similar concluding sentence*).

MITES Student Projects

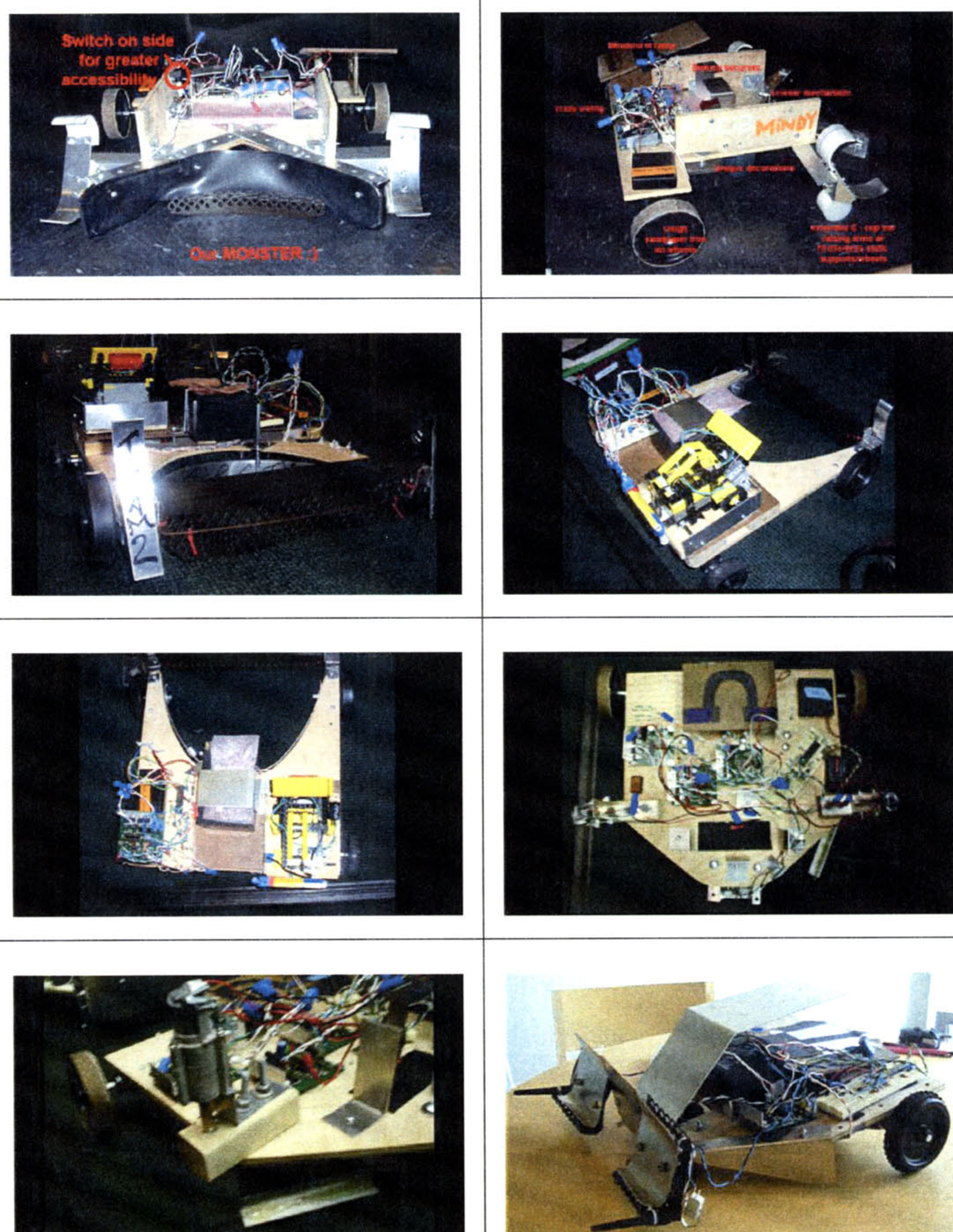


Figure 4-10: Semi-Autonomous robots designed and built by MITES students in teams of 4 over 5 weeks - approximately 5 work hours per week.

MITES Student Projects

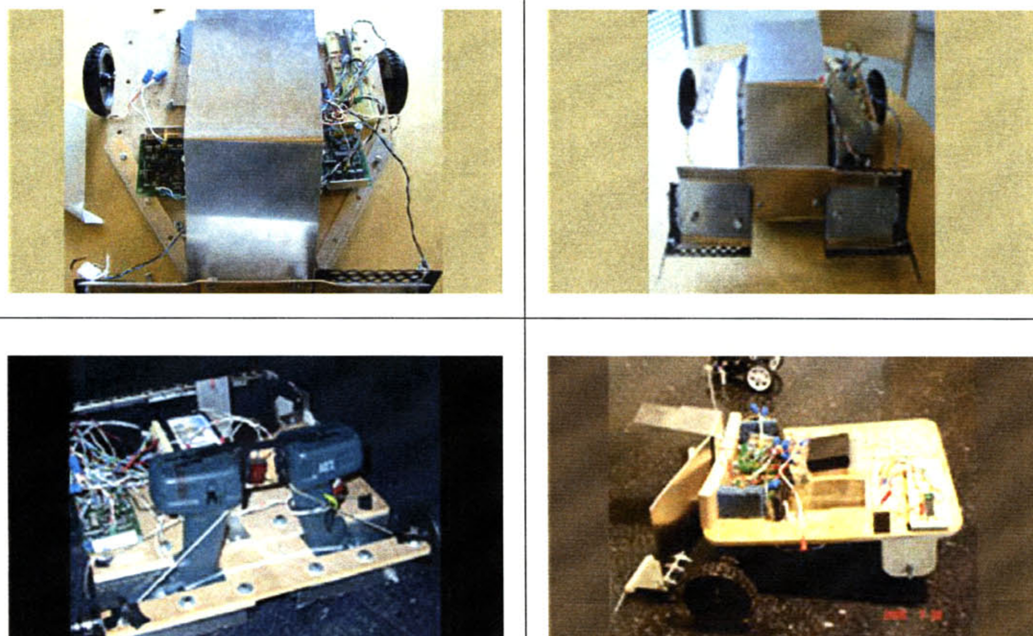


Figure 4-10: Semi-Autonomous robots designed and built by MITES students in teams of 4 over 5 weeks - approximately 5 work hours per week.

4.2.3 The Second Summer Program (MIT course 2.971)

The Second Summer Program introduces students to Deterministic Design with PREP, by application of fundamental principles and learning to complete projects according to schedule and within budget. Students rely on active learning through a major team-based design-and-build project focused on the need for a new consumer product identified by each team. Topics learned while teams create, design, build, and test their product ideas include: formulating strategies, concepts and modules, and estimation, concept selection, machine elements, design for manufacturing, visual thinking, communication, teamwork and professional responsibilities. In 2006, questionnaires (see APPENDIX A: SECOND SUMMER PROGRAM STUDENTS SURVEY) were distributed to students who took the course from 2001-2006. The average response and unbiased standard of deviation (eq. 4.1) for each question are displayed in Table 4-2.

$$\text{eq. 4.1} \qquad \text{Standard of Deviation (unbiased)} = \sqrt{\frac{\Sigma(x-\bar{x})^2}{(n-1)}}$$

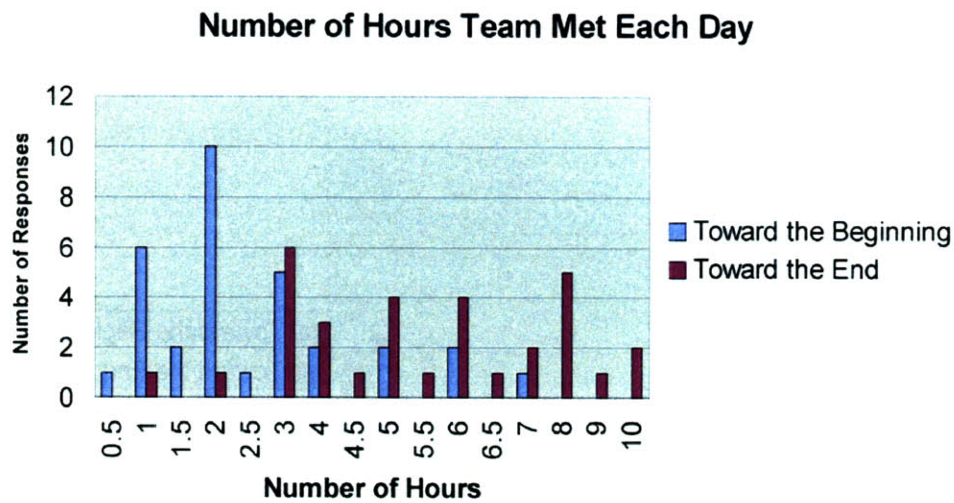
Average Response and Standard of Deviation to Second Summer Survey Questions				
Questions			**Rating**	**STDEV (n-1)**
How many hours per day average did your team meet?	Toward the beginning		**2.63**	**1.65**
	Toward the end		**5.52**	**2.34**
How many hours per day average did your team spend in the machine shop?	Toward the beginning		**0.84**	**0.87**
	Toward the end		**3.44**	**1.90**
How many hours per day average did you spend independently problem solving and/or designing?	Toward the beginning		**2.05**	**1.44**
	Toward the end		**2.25**	**2.17**
How many hours per day average did you spend independently in the machine shop?	Toward the beginning		**0.23**	**0.48**
	Toward the end		**1.60**	**2.05**
How would you rate your team's overall collaboration?	Toward the beginning		**76.5%**	**21.6%**
	Toward the end		**90.2%**	**15.2%**
Did the extent of team collaboration have an impact on your performance?	Toward the beginning	Rate 1 Absolutely to 7 Not at All	**2.38**	**1.60**
	Toward the end	Rate 1 Absolutely to 7 Not at All	**1.66**	**1.00**
How would you rate your personal teamwork effort?	Toward the beginning		**82.6%**	**22.1%**
	Toward the end		**87.9%**	**18.9%**
How comfortable did you feel presenting your ideas to the rest of the team?	Toward the beginning		**87.9%**	**20.8%**
	Toward the end		**93.9%**	**14.0%**
Do you agree your contributions were recognized by your teammates?	Toward the beginning		**82.0%**	**22.2%**
	Toward the end		**86.7%**	**21.1%**
Do you agree your Second Summer Program experience prepared you for a summer internship?	Rate 1 Strongly Agree to 7 Strongly Disagree		**3.03**	**1.47**
Do you agree your Second Summer Program experience helped you become a better student?	Rate 1 Strongly Agree to 7 Strongly Disagree		**2.97**	**1.66**
How satisfied were you with the course?	Rate 1 Unsatisfied to 7 Satisfied		**4.94**	**1.84**
Since completion of the Second Summer Program, how often do you apply PREP phases 1) Individual Thought, 2) Peer-Review, and 3) Group Discussion in your work with others?	Percentage		**54.9%**	**26.5%**

Table 4-2: Second Summer Program Student Question 2001-2006

The data indicates high and/or increasing team collaboration over time. This may be due to the team naturally growing closer. I believe it is largely a result of the process demanding the involvement of all members throughout the entire process. There is also an increase in the contribution of individual team members to the team throughout development. Team collaboration strongly impacted individual performance and team members were overwhelmingly comfortable with their teammates. Students indicated above average satisfaction with the course and agreed that the program not only helped prepare them for a summer internship, but also helped them become better students. Since completion of the program, when working with others over 45% use PREP 75% of the time and over 75% use PREP at least 50% of the time.

Figure 4-11 on page 61 - Figure 4-23 on page 73 display responses to surveys submitted in 2006 by students from program years 2001-2006. Responses to every question by year are displayed in APPENDIX B: SECOND SUMMER PROGRAM SURVEY RESPONSES. For each set of responses, an opinion is given on the effect that Deterministic Design with PREP had, along with possible covariants that may have led to the results. Responses to questions regarding time commitments, individual performance, team collaboration, improvement of study habits, and continued use of PREP were all impressive.

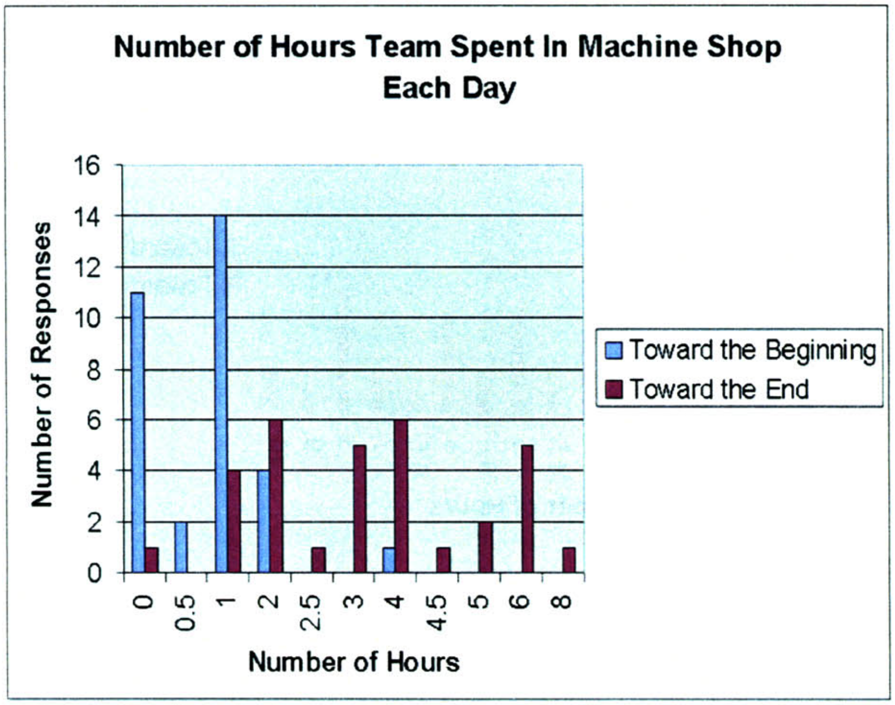
Number of Hours Teams Met Toward the Beginning of the Course vs. Toward the End of the Course 2001-2006



Class	• Second Summer Program - MIT Course 2.971
Years	• 2001-2006
Type	• Product Development by Deterministic Design with PREP
# of Students	• Year 2001 - 42 Students • Year 2002 - 27 Students • Year 2003 - 28 Students • Year 2004 - 29 Students • Year 2005 - 19 Students • Year 2006 - 10 Students
# of Responses	• 32
Trend	• Number of hours increased over time
Effect of Deterministic Design & PREP (opinion)	• Comfort between teammates increases over time
Possible Covariants	• Slow start results in workload increase over time • Difficult project • Poor scheduling early on

Figure 4-11: Number of Hours Team Met Each Day

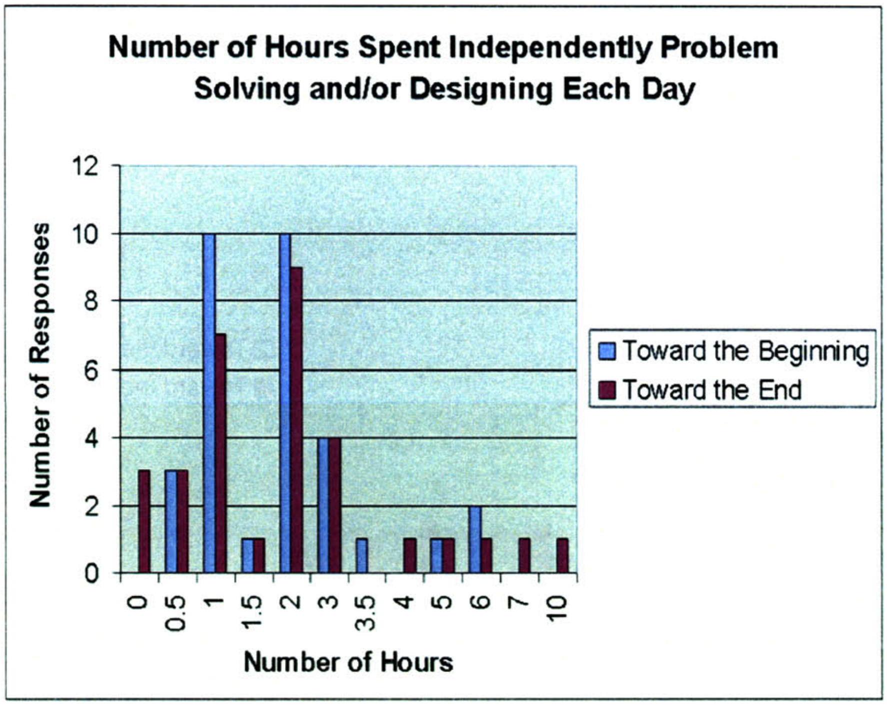
Number of Hours Teams Spent In Machine Shop Toward the Beginning of the Course vs. Toward the End of the Course 2001-2006



Class	• Second Summer Program - MIT Course 2.971
Years	• 2001-2006
Type	• Product Development by Deterministic Design with PREP
# of Students	• Year 2001 - 42 Students • Year 2002 - 27 Students • Year 2003 - 28 Students • Year 2004 - 29 Students • Year 2005 - 19 Students • Year 2006 - 10 Students
# of Responses	• 32
Trend	• ~1hr/day average toward the beginning ~3.5hrs/day average toward the end
Effect of Deterministic Design & PREP (opinion)	• Bench level experiments minimize early machining time • Equal division of work keeps machining time tolerable
Possible Covariants	• Expert machine shop assistance keeps machining time tolerable

Figure 4-12: Number of Hours Team Spent In Machine Shop Each Day

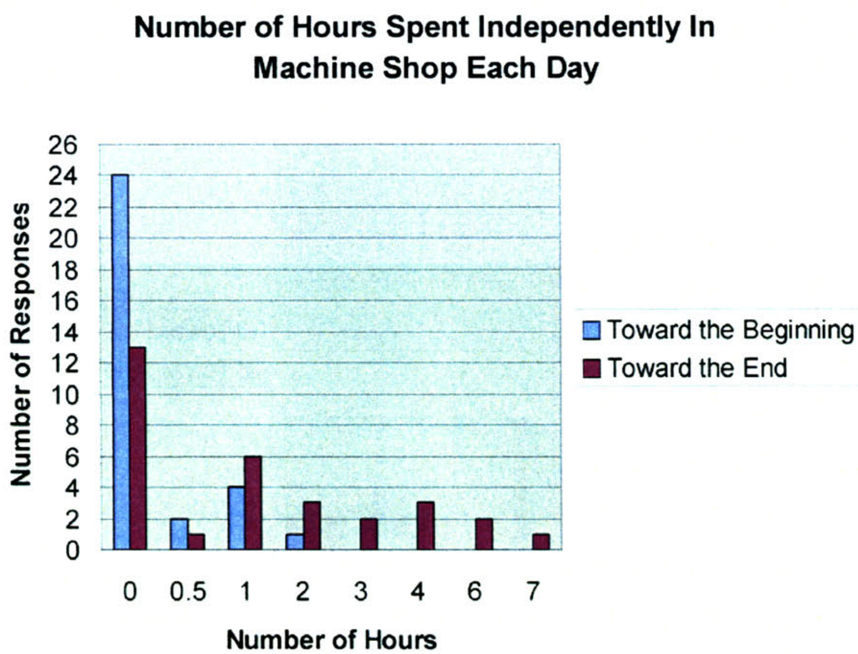
Number of Hours Spent Independently Problem Solving and/or Designing Toward the Beginning of the Course vs. Toward the End of the Course 2001-2006



Class	• Second Summer Program - MIT Course 2.971
Years	• 2001-2006
Type	• Product Development by Deterministic Design with PREP
# of Students	• Year 2001 - 42 Students • Year 2002 - 27 Students • Year 2003 - 28 Students • Year 2004 - 29 Students • Year 2005 - 19 Students • Year 2006 - 10 Students
# of Responses	• 32
Trend	• Average 2 - 2.5hrs/day
Effect of Deterministic Design & PREP (opinion)	• Individual Thought stage of PREP keeps individual work consistent throughout development
Possible Covariants	• Amount of time able to commit to course; course scheduling by hour blocks

Figure 4-13: Number of Hours Spent Independently Problem Solving and/or Designing Each Day

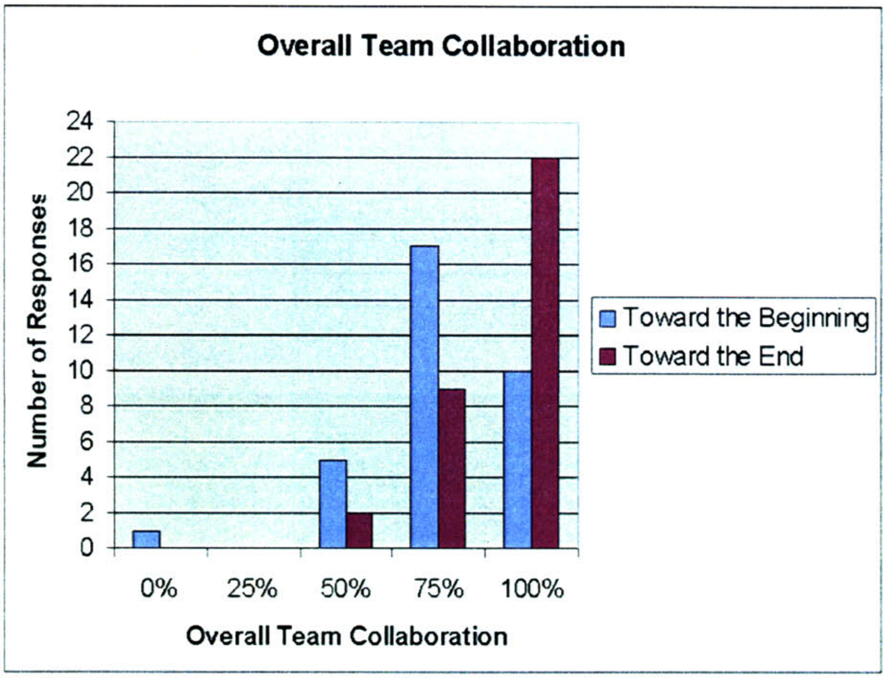
Number of Hours Spent Independently In Machine Shop Toward the Beginning of the Course vs. Toward the End of the Course 2001-2006



Class	• Second Summer Program - MIT Course 2.971
Years	• 2001-2006
Type	• Product Development by Deterministic Design with PREP
# of Students	• Year 2001 - 42 Students • Year 2002 - 27 Students • Year 2003 - 28 Students • Year 2004 - 29 Students • Year 2005 - 19 Students • Year 2006 - 10 Students
# of Responses	• 31
Trend	• Slight increase over time
Effect of Deterministic Design & PREP (opinion)	• Average individual work hours in shop are about 1/3 to 1/2 the team work hours in shop; Good team time management/scheduling
Possible Covariants	• Some members do no independent machining

Figure 4-14: Number of Hours Spent Independently In Machine Shop Each Day

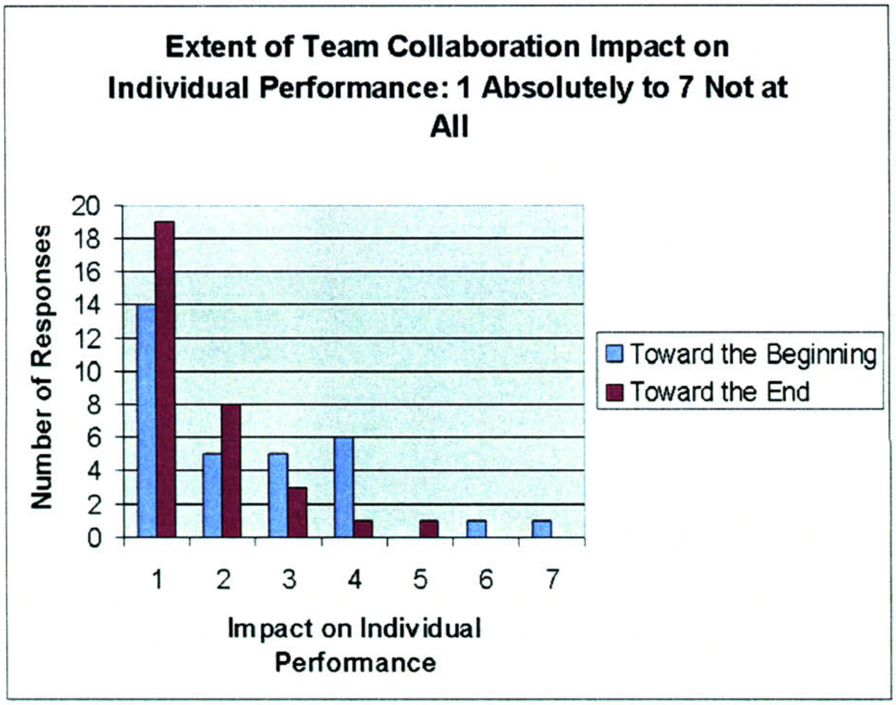
Overall Team Collaboration Toward the Beginning of the Course vs. Toward the End of the Course 2001-2006



Class	• Second Summer Program - MIT Course 2.971
Years	• 2001-2006
Type	• Product Development by Deterministic Design with PREP
# of Students	• Year 2001 - 42 Students • Year 2002 - 27 Students • Year 2003 - 28 Students • Year 2004 - 29 Students • Year 2005 - 19 Students • Year 2006 - 10 Students
# of Responses	• 33
Trend	• Remains high and/or increases over time
Effect of Deterministic Design & PREP (opinion)	• Process requires large collaboration
Possible Covariants	• Team members like each other • Strong interest in project

Figure 4-15: Overall Team Collaboration

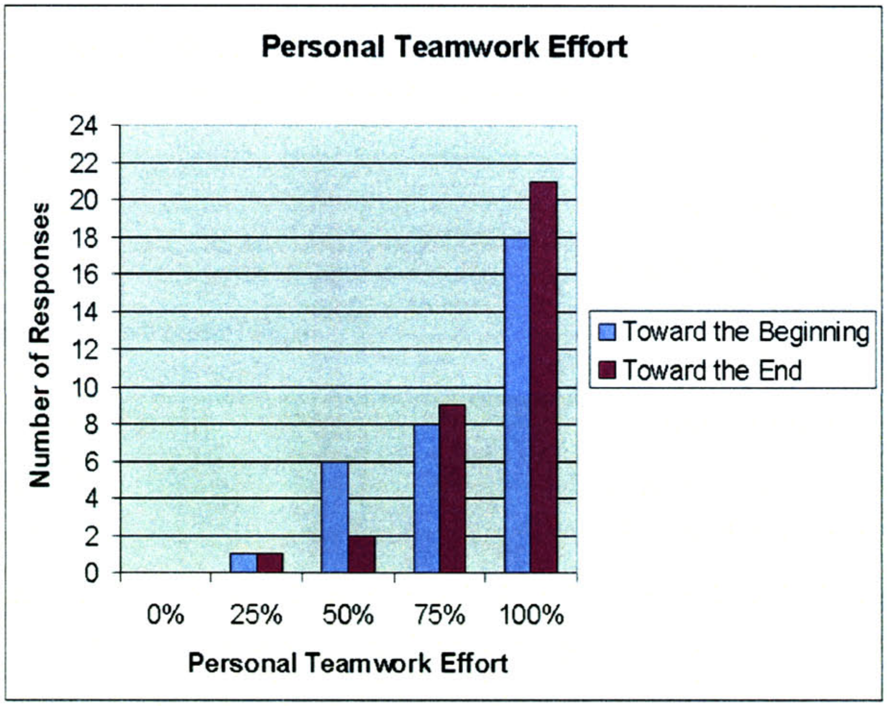
Extent of Team Collaboration Impact on Individual Performance Toward the Beginning of the Course vs. Toward the End of the Course 2001-2006



Class	• Second Summer Program - MIT Course 2.971
Years	• 2001-2006
Type	• Product Development by Deterministic Design with PREP
# of Students	• Year 2001 - 42 Students • Year 2002 - 27 Students • Year 2003 - 28 Students • Year 2004 - 29 Students • Year 2005 - 19 Students • Year 2006 - 10 Students
# of Responses	• 32
Trend	• Remains high and/or increases over time
Effect of Deterministic Design & PREP (opinion)	• Frequent Peer-Review has strong impact
Possible Covariants	• Highly intelligent students • Helpful students

Figure 4-16: Extent of Team Collaboration Impact on Individual Performance

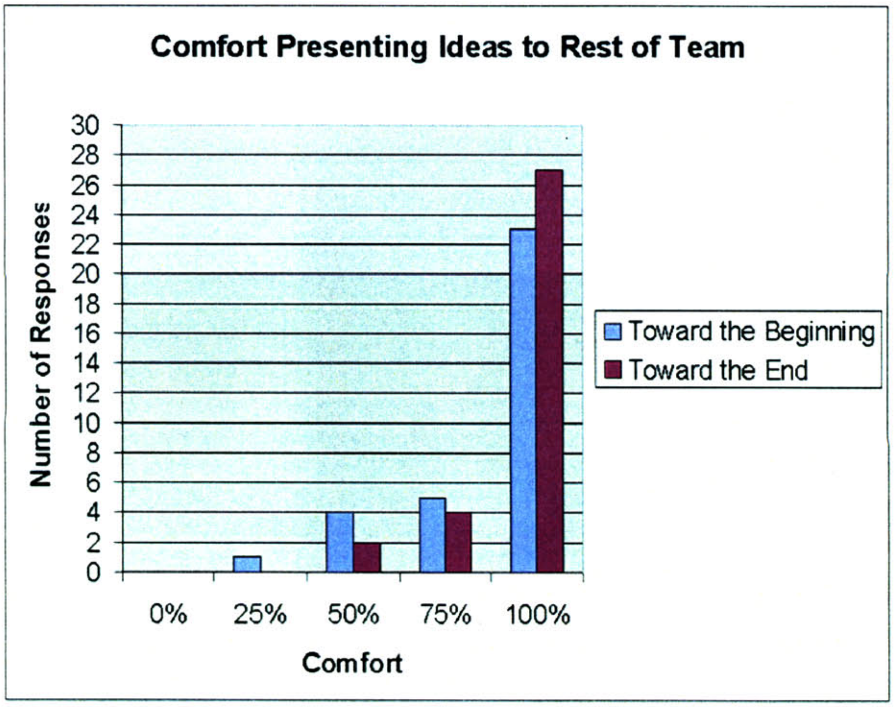
Personal Teamwork Effort Toward the Beginning of the Course vs. Toward the End of the Course 2001-2006



Class	• Second Summer Program - MIT Course 2.971
Years	• 2001-2006
Type	• Product Development by Deterministic Design with PREP
# of Students	• Year 2001 - 42 Students • Year 2002 - 27 Students • Year 2003 - 28 Students • Year 2004 - 29 Students • Year 2005 - 19 Students • Year 2006 - 10 Students
# of Responses	• 33
Trend	• Remains high and/or increases over time
Effect of Deterministic Design & PREP (opinion)	• Individual Thought and Peer-Review require continuous input
Possible Covariants	• Highly motivated students

Figure 4-17: Personal Teamwork Effort

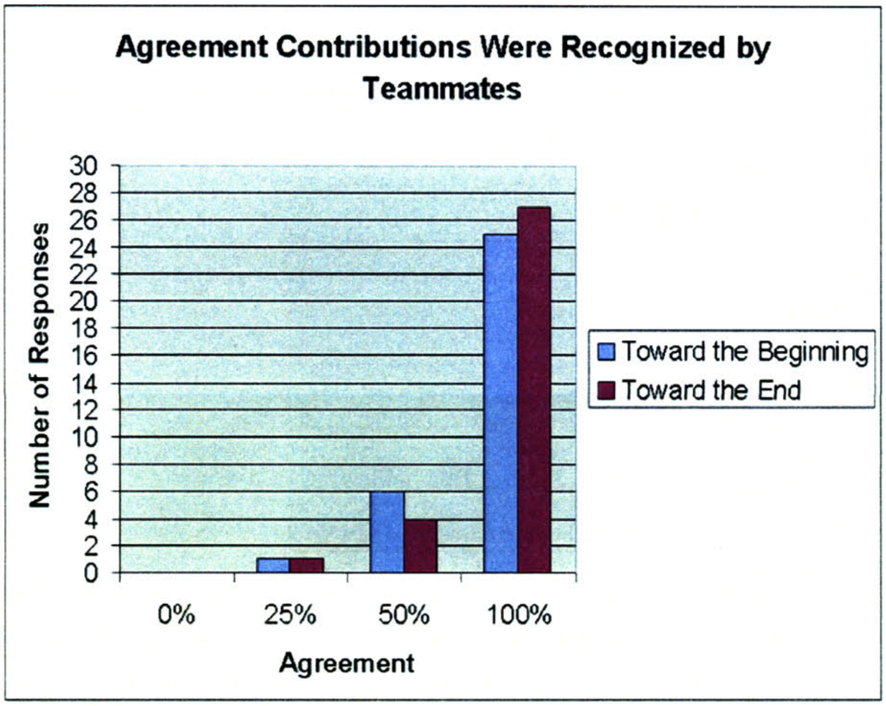
Comfort Presenting Ideas to Rest of Team Toward the Beginning of the Course vs. Toward the End of the Course 2001-2006



Class	• Second Summer Program - MIT Course 2.971
Years	• 2001-2006
Type	• Product Development by Deterministic Design with PREP
# of Students	• Year 2001 - 42 Students • Year 2002 - 27 Students • Year 2003 - 28 Students • Year 2004 - 29 Students • Year 2005 - 19 Students • Year 2006 - 10 Students
# of Responses	• 33
Trend	• Remains high and/or increases over time
Effect of Deterministic Design & PREP (opinion)	• Receptive process
Possible Covariants	• Nice and/or easy going students

Figure 4-18: Comfort Presenting Ideas to Rest of Team

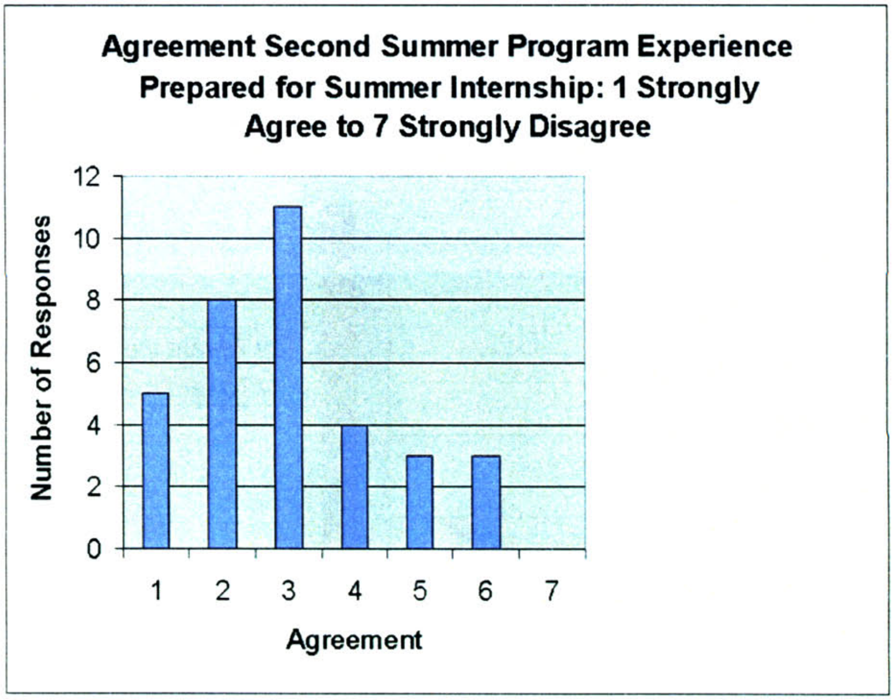
Agreement Contributions Were Recognized by Teammates Toward the Beginning of the Course vs. Toward the End of the Course 2001-2006



Class	• Second Summer Program - MIT Course 2.971
Years	• 2001-2006
Type	• Product Development by Deterministic Design with PREP
# of Students	• Year 2001 - 42 Students • Year 2002 - 27 Students • Year 2003 - 28 Students • Year 2004 - 29 Students • Year 2005 - 19 Students • Year 2006 - 10 Students
# of Responses	• 32
Trend	• Remains high and/or increases over time
Effect of Deterministic Design & PREP (opinion)	• Receptive process
Possible Covariants	• Respectful students

Figure 4-19: Agreement Contributions Were Recognized by Teammates

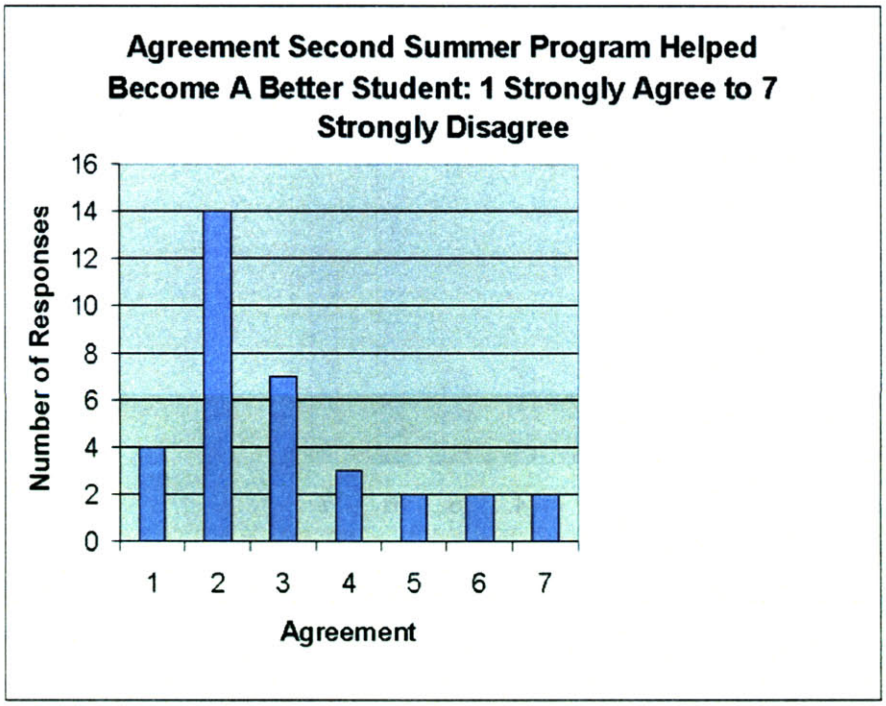
Agreement Second Summer Program Experience Prepared for Summer Internship - Strongly Agree to Strongly Disagree 2001-2006



Class	• Second Summer Program - MIT Course 2.971
Years	• 2001-2006
Type	• Product Development by Deterministic Design with PREP
# of Students	• Year 2001 - 42 Students • Year 2002 - 27 Students • Year 2003 - 28 Students • Year 2004 - 29 Students • Year 2005 - 19 Students • Year 2006 - 10 Students
# of Responses	• 34
Trend	• Over 65% agreement
Effect of Deterministic Design & PREP (opinion)	• Process demonstrates technique for working in teams
Possible Covariants	• Teamwork experiences prepare students for summer internships

Figure 4-20: Agreement Second Summer Program Experience Prepared for Summer Internship

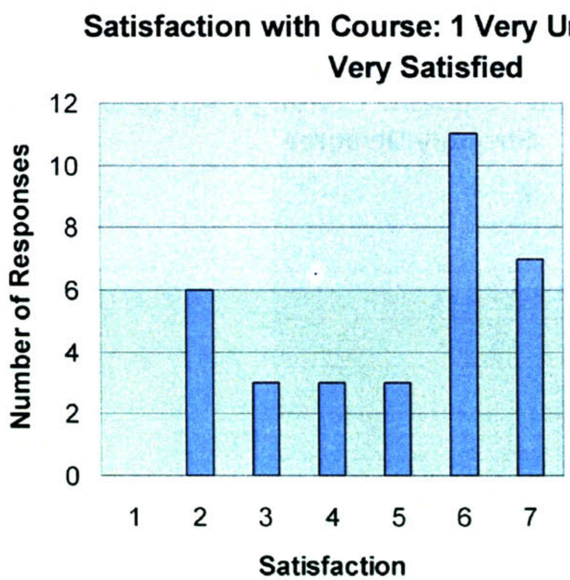
Agreement Second Summer Program Experience Prepared for Summer Internship - Strongly Agree to Strongly Disagree 2001-2006



Class	• Second Summer Program - MIT Course 2.971
Years	• 2001-2006
Type	• Product Development by Deterministic Design with PREP
# of Students	• Year 2001 - 42 Students • Year 2002 - 27 Students • Year 2003 - 28 Students • Year 2004 - 29 Students • Year 2005 - 19 Students • Year 2006 - 10 Students
# of Responses	• 34
Trend	• Over 65% agreement
Effect of Deterministic Design & PREP (opinion)	• Process is transferable to other disciplines
Possible Covariants	• Challenging work makes for better students

Figure 4-21: Agreement Second Summer Program Experience Prepared for Summer Internship

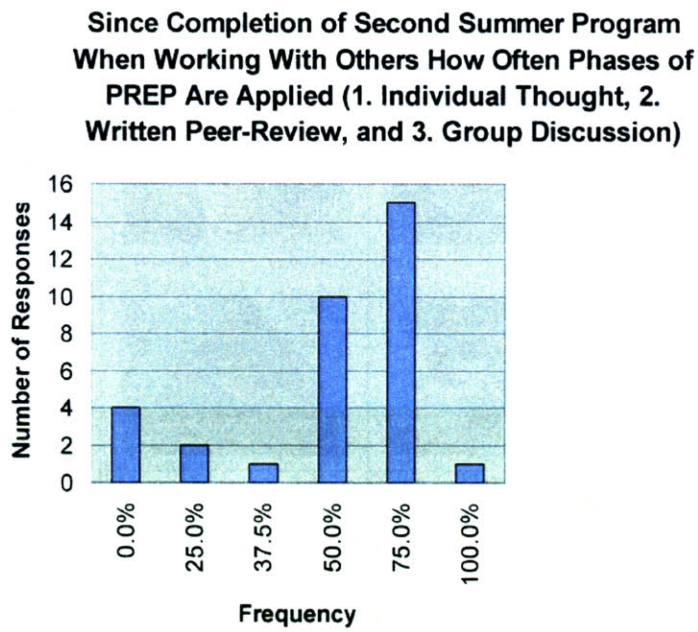
Satisfaction with Course - Very Unsatisfied to Very Satisfied 2001-2006



Class	• Second Summer Program - MIT Course 2.971
Years	• 2001-2006
Type	• Product Development by Deterministic Design with PREP
# of Students	• Year 2001 - 42 Students • Year 2002 - 27 Students • Year 2003 - 28 Students • Year 2004 - 29 Students • Year 2005 - 19 Students • Year 2006 - 10 Students
# of Responses	• 33
Trend	• Over 60% satisfaction
Effect of Deterministic Design & PREP (opinion)	• Limits aggressiveness of students • Provides equal ground for potentially disadvantaged populations (minorities, women, introverts, and disabled)
Possible Covariants	• Students like their teammates • Students like the instructors/TAs

Figure 4-22: Satisfaction with Course

How Often Continue to Apply PREP When Working with Others 2001-2006



Class	• Second Summer Program - MIT Course 2.971
Years	• 2001-2006
Type	• Product Development by Deterministic Design with PREP
# of Students	• Year 2001 - 42 Students • Year 2002 - 27 Students • Year 2003 - 28 Students • Year 2004 - 29 Students • Year 2005 - 19 Students • Year 2006 - 10 Students
# of Responses	• 33
Trend	• Over 45% use PREP 75% of the time, over 75% user PREP at least 50% of the time
Effect of Deterministic Design & PREP (opinion)	• Provides an effective approach to teamwork
Possible Covariants	• Individual Thought, Peer-Review, and then Discussion is a preferred approach for most people when working in teams • Users have learned no other processes for working in teams

Figure 4-23: How Often Continue to Apply PREP When Working with Others

Examples of Second Summer Program projects from 2003-2006 are displayed in the figures that follow.

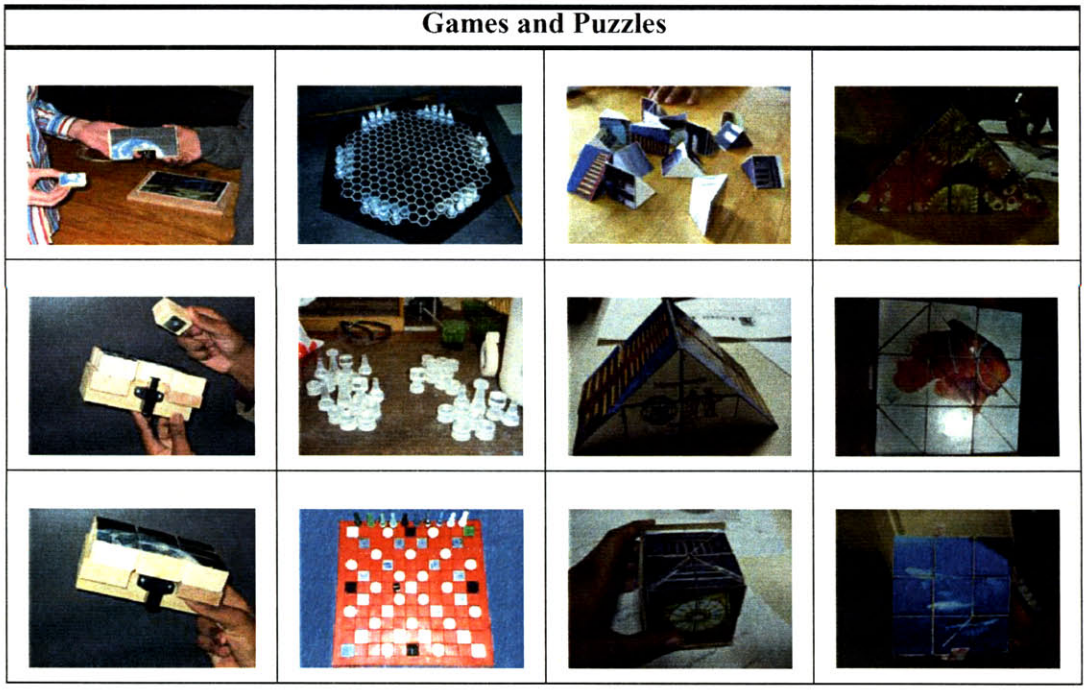


Figure 4-24: Second Summer Projects 2003 - Changing Image Puzzle, Six Player Chess Game, Detective Board Game, Multi-shape 3D Puzzles

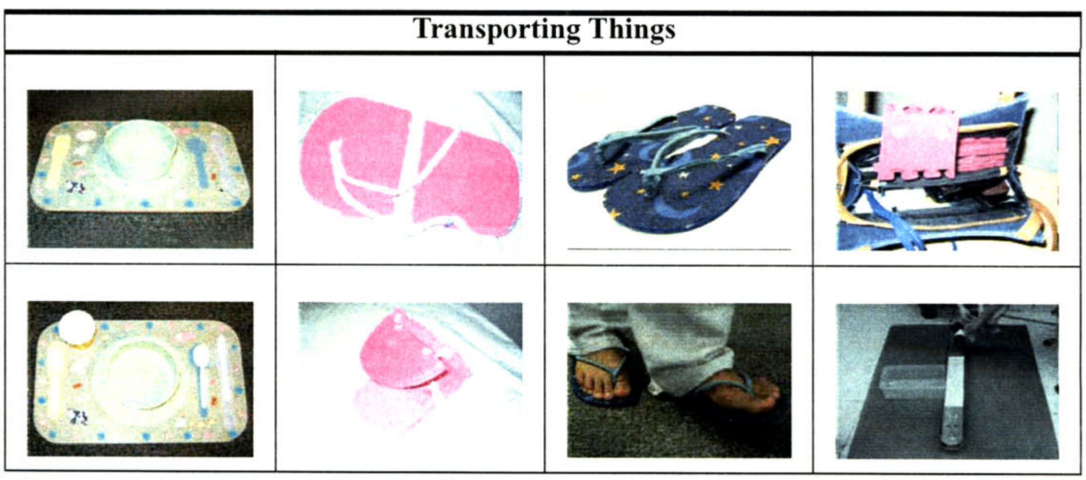


Figure 4-25: Second Summer Projects 2004 - Dish Locking Children's Food Tray, Folding/Collapsible Sandals, Under-bed Shoe Tram, Rollaway Laundry Baskets

Transporting Things

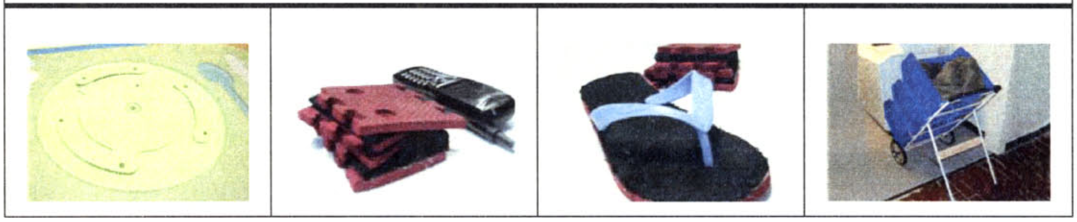


Figure 4-25: Second Summer Projects 2004 - Dish Locking Children's Food Tray, Folding/Collapsible Sandals, Under-bed Shoe Tram, Rollaway Laundry Baskets

Learning Tools

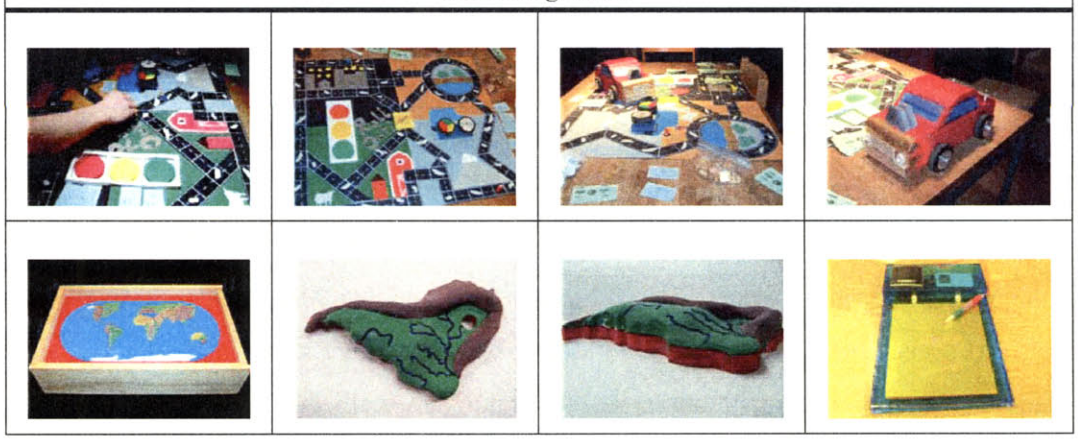


Figure 4-26: Second Summer Projects 2005 - Driver Education Board Game, Interactive Educational Puzzle, Handwriting Trainer

Office Products

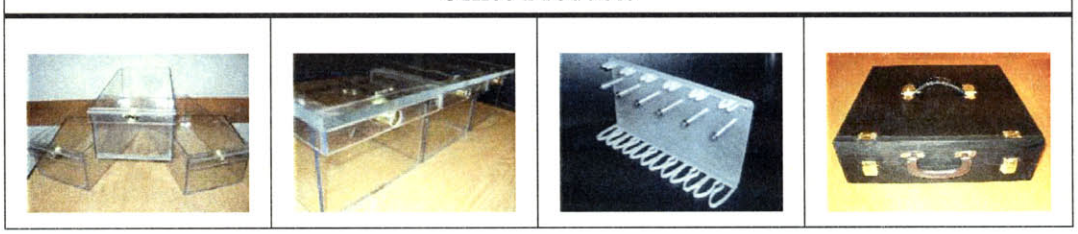


Figure 4-27: Second Summer Projects 2006 - Securable Refrigerator Drawers, Cable/Wiring Management Device, Collapsible Office Shelf Briefcase

4.2.4 Design and Manufacturing I (MIT course 2.007)

Design and Manufacturing I develops students' competence and self-confidence as design engineers. Emphasis is on the creative design process bolstered by application of physical laws, and learning to complete projects on schedule and within budget. Synthesis, analysis, design robustness and manufacturability are emphasized. The subject relies on active learning via a major design-and-build project. Lecture topics include idea generation, estimation, concept selection, visual thinking and communication, kinematics of mechanisms, machine elements, design for manufacturing, basic electronics, and professional responsibilities and ethics. A required on-line evaluation is given at the beginning and the end of the course, so students can assess their design knowledge.

The design of the competition table for the course is a collaborative effort between teaching assistants, students from the previous year, and technical instructors (see Figure 4-28). The table itself was design using Deterministic Design with PREP. The objective in designing the table is to have numerous ways to score, so that the scoring function is a multiple of points earned by completing various obstacles. This makes students more likely to design for more than one functional requirement, resulting in machines built in modules. Many student module ideas are similar and peer-review teams may be formed based on strategy similarities. Some students are hesitant to share their ideas with others, but those that do usually benefit from peer-review. I find that most student comments are not malicious and respect and constructive criticism are encouraged.

Figure 4-28: 2004 2.007 Competition Table

Deterministic Design with PREP is covered in lecture, along with machine elements. Review teams are formed in lab sections, which take place once a week. Students individually design their machines before meeting with their teams for review. PREP is completed before coming to lab and each stage of development is submitted to the lab instructor as a milestone. Completing solid models of machines is strongly encouraged (instead of hand drawings). Solid models should closely resemble the final machine designs (see Figure 4-29).

Machine Designs

Figure 4-29: Machines designed and built by 2.007 students in 2004

4.2.5 Creative Deterministic Composition: Poetry in Progress (MIT course SP2H1)

I adapted Deterministic Design with PREP to be used for creative writing. After close to two decades of writing and performing and over a decade of engineering design, I noticed that more and more I was using a process similar to Deterministic Design with PREP when writing.

Creative writers develop works to please an audience much like designers develop products to please customers. Designers follow development processes that include customer feedback throughout. However, many creative writers keep their work hidden until they feel it is ready for presentation, often experiencing undesirable results. I developed a writing course[8] in the MIT Experimental Studies Group (ESG), Creative Deterministic Composition (evolved from Deterministic Design), in which students write based on audience requirements and receive feedback from their audience at each stage of development from topic to delivery/presentation.

Early in the course, students are placed in teams. Poem writing is broken into four stages: 1) Topics, 2) Sub-topics, 3) Line-by-Lines, and 4) Complete Poem. Students first develop a list of topics they are interested in developing. The topics are peer-reviewed and discussed to determine which one peers/customers are most interested in being developed. Once a topic is determined, a list of detailed sub-topics is developed for the topic. The list of sub-topics should include anything and everything that can possibly be included to develop the topic. The list of sub-topics is peer-reviewed and discussed to determine which sub-topics the peers/customers are interested in being used to develop the topic. After determining sub-topics, the writer writes lines for each sub-topic. The lines are peer-reviewed and feedback is given about what works or does not work, along with suggestions for improvement. Once, the line-by-lines have been peer-reviewed and discussed, poems are written (assembled), peer-reviewed, discussed and revised. This follows the same process as Deterministic Design, which occurs in three phases strategy, concept, and modules, followed by assembly and testing.

Each stage is of equal importance, beginning with the topic. If the topic is not of interest, the poem will not be interesting. Just as with product design, before developing a poem, the writer makes sure that the peer group/customers are in agreement. The same scrutiny is required for sub-topics, line-by-lines, and the final poem. As writers become more experienced, the transition from topics to final poem becomes more direct (i.e. sub-topic and line-by-line listing are increasingly grouped with topic development and final poem writing respectively). The objective is to learn how to write for an audience, just as a designer learns to design for a customer. The

8. Assisted by Prof. Mary Fuller at MIT, http://pergatory.mit.edu/jotls/cdc.htm

writer first learns his/her audience and then learns to write for that audience, as designers identify market needs and design to meet those needs. In creative writing and design, it is important to keep the audience/customer in the loop. Some may say that artists create for themselves, based on personal inspiration, so the first step is not needed. However, the first step helps ensure that what the artists chooses to develop will be wanted by others as well, which is necessary to generate income.

There was collaboration with iCampus the MIT-Microsoft Alliance to develop a Microsoft SharePoint web portal for PREP. The portal allows instructors to post assignments as a matrix, where students can post their work to be reviewed by teammates. The portal keeps track of when assignments were posted and due dates. It also displays if students have posted their work and if they are reviewing or have reviewed the work of others. There is also a discussion board on the portal for discussing work after peer-review. However, while students were very happy to use the portal for peer-review, they largely preferred to have group discussion in person. All of the students taking the course were Instant Messenger users, which leads me to believe they prefer peer-to-peer Internet interaction as opposed to peer group Internet interaction. The reality is that live discussion is more effective than the virtual approach offered by the portal. The addition of web cameras to the discussion board may make it more useful.

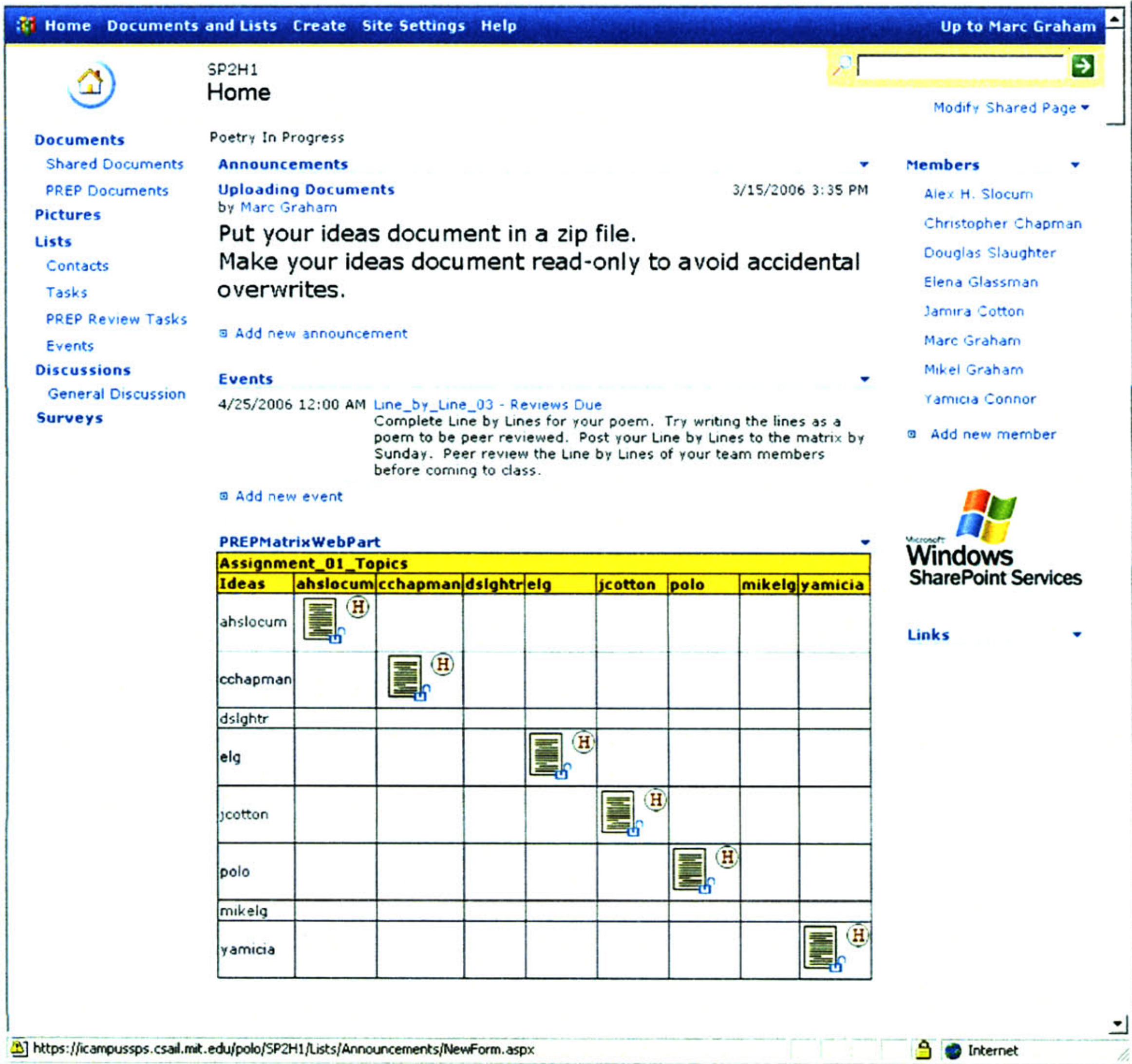


Figure 4-30: PREP Portal for Creative Deterministic Composition - Poetry in Progress

A simplified display of the matrix is shown in Figure 4-30. It indicates that six students have posted documents for review. When the matrix is set up for a PREP assignment, black dots are placed at the intersection of the student's name that posted the document and all peers that must review the document. When a document is checked out to a peer, the black dot becomes a yellow dot. And when a document has been reviewed and returned to the portal, a green check is displayed (see Figure 4-31). Multiple dots appear when a document has been posted multiple times.

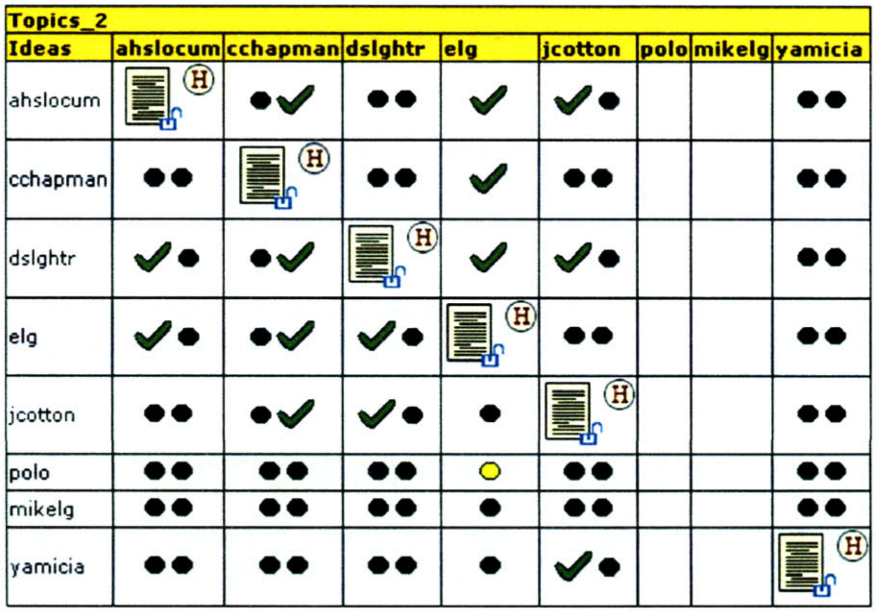


Figure 4-31: PREP Portal Matrix for peer-reviewed assignments

4.2.6 NASA Research In Science and Engineering (NASA RISE)

National Aeronautics and Space Administration Research In Science and Engineering is a program for talented college and university students focused on preparation for graduate school. A typical weekly schedule is displayed in Table 4-3. NASA RISE is all-inclusive but generally attracts mostly minority students. For two years, Deterministic Design with PREP was taught to NASA RISE students. Students completed mosaic tile designs as done in Pathways to Peace and Rube Goldberg projects.

MIT OFFICE OF MINORITY EDUCATION
Week Three

July 7 - July 13	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
7:00 - 8:15 AM	Breakfast	Breakfast	Breakfast	Breakfast	Breakfast	Breakfast	Breakfast
8:30 - 9:30 AM	Review/Writing	Review/Writing	Review/Writing	Review/Writing	Review/Writing	BEACH FIELD TRIP	
9:30 - 10:30 AM	PowerPoint	Excel	SolidWorks	GRE Prep	Presentations		
10:30 - 11:00 AM	Break	Break	Break	Break	Break		
11:00AM - NOON	PowerPoint	Excel	HTML	HTML	HTML		
NOON - 1:00 PM	Lunch	Lunch	Lunch	Lunch	Lunch		
1:00 - 2:30 PM	Physics/ Calculus	GRE Prep	Physics/ Calculus	GRE Prep	Physics/ Calculus		
2:45 - 5:00 PM	Research w/ Grad Student	Research w/ Grad Student	Research w/ Grad Student	Research w/ Grad Student	Research w/ Grad Student		
5:00 -6:30 PM	Team work	Staff Meeting	Team work	Meet w/ Dean	Team work		
8:00 - 10:30 PM	Dinner	Dinner	Dinner	Dinner	Dinner		Dinner
10:30 PM - MIDNIGHT	Journal & Study	Journal & Study	Journal & Study	Journal & Study	Journal & Study		

Table 4-3: Typical weekly schedule for NASA RISE

Mosaic Tiles & Rube Goldberg Project

Figure 4-32: Mosaic Tiles - Science, Engineering, Space and Diversity; Rube Goldberg Project - 10 Steps to Stop an Alarm Clock

After completing NASA RISE, the students return to their respective colleges. The majority of students who complete the program attend graduate school.

4.2.7 Pathways to Peace (MIT course 2.993)

Pathways to Peace teaches creative design through the design, engineering, and manufacture of a detailed inlaid tile. This is an introductory lecture/studio course designed to teach students the basic principles of design and expose them to the design process. Throughout the course, students are introduced to the terminology and concepts that underlie all forms of visual art, which in many ways forms the basis for the design of all physical objects. Along with learning mechanical skills, thinking both critically and visually, and working with different media, students consider how the arts grow out of and respond to particular cultural contexts and ideas, and how these thinking patterns can be applied to virtually all types of design. Presentations, lectures, demonstrations, discussions and various artistic works are used to show students how other artists and designers have dealt with the same issues they face in lab.

Mosaic Tiles and Sculpture

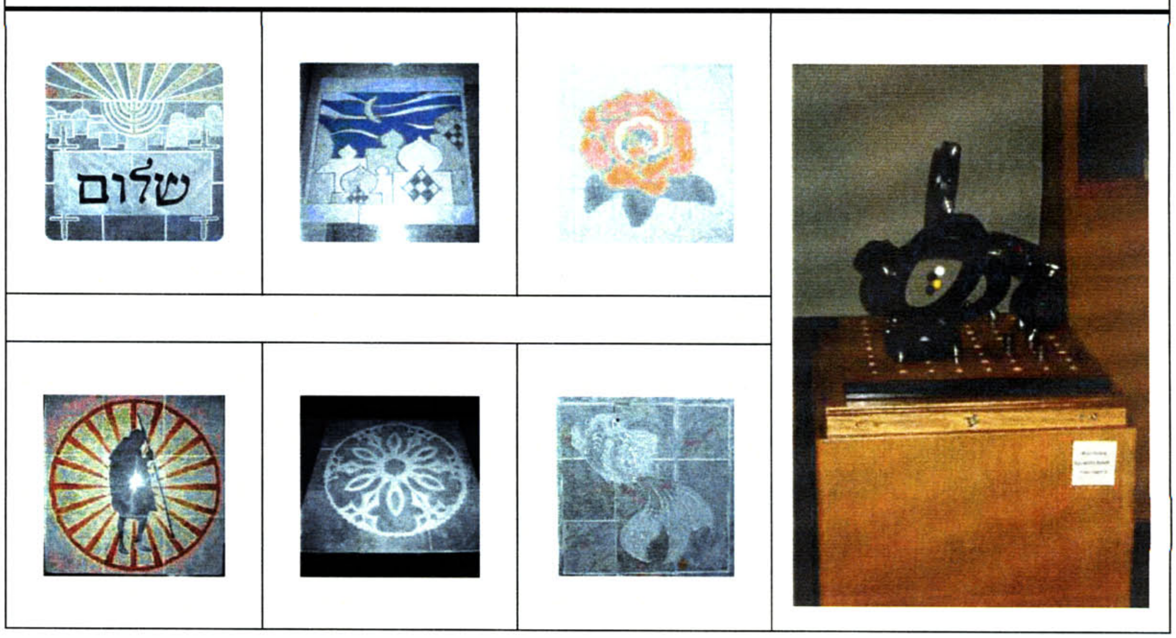


Figure 4-33: Mosaic Tiles - Religion and Culture; Sculpture - Repositioning (Interactive) Artwork

4.2.8 Physics I, Technology-Enabled Active Learning (MIT course 8.01T)

In Physics I, students are introduced to classical mechanics: space and time, straight-line kinematics, motion in a plane, forces, and static equilibrium, particle dynamics with force and conservation of momentum, relative inertial frames and non-inertial force, work, potential energy and conservation of energy, kinetic theory and the ideal gas, rigid bodies and rotational dynamics, vibrational motion, conservation of angular momentum, central force motions, and fluid mechanics. The subject is taught using the TEAL (Technology Enabled Active Learning) format which features small group interaction via table-top experiments utilizing lap-tops for data acquisition and problem solving workshops.

For one semester the course included a design section, where students solved physics problems associated with the competition table for Design and Manufacturing I (see Figure 4-28). The purpose was for students to learn to use physics to solve engineering problems, as would be necessary for many of them in their academic and professional careers. Though a good idea, the addition to the course was not well implemented and also presented a workload to the students that was more demanding than what was offered in course credits. As a result, few students completed the additional work on problem sets.

5 DESIGNING DESIGNERS

5.1 How Young Is Too Young?

Design is a problem solving process that can and should be learned early in life. Engineers are problem solvers that use knowledge of math and science to make rational problem solving decisions. However, all problems are not technical, requiring advanced math and science skills to be solved. To teach design at an early age, presented problems should deal with topics with which students have experience. Design problems presented to students should become more sophisticated as students become more technically advanced. Primary level students can begin with creative writing. Secondary level students can design toys, games and puzzles. And more advanced students can practice machine design or book writing. In addition, it is not necessary for all projects to be mechanically focused. Other disciplines can and should be explored as well. Skills for planning, styling and development of ideas, or concepts into a working structure, or program are transferable. And regardless of how sophisticated design projects are, they can be completed using Deterministic Design with PREP. Students can perfect team-working and design skills before they are technically advanced.

Early in education, students can begin working in groups using PREP. They can develop creative skill by coupling it with Deterministic Design. Fundamentals are generally taught before introducing individuals to advanced studies. Deterministic Design and PREP are fundamentals of engineering design and teamwork. High school graduates are not expected to struggle when solving simple mathematics problems, as students familiar with Deterministic Design and PREP should not be expected to struggle with solving simple design problems and teamwork. As early as students begin learning math and science, they can be learning Deterministic Design and how to work in groups using PREP.

I have found that having some engineering background prior to learning PREP facilitates its use in engineering design work. And it shows that for individuals to be more successful in design, in general, math and science training hones the brain's skills to think rationally, which is needed to add to sheer creativity in order to complete a design and bring it to market. Students having completed calculus and physics are able to design deterministically, but not as effectively as students who have had calculus, physics and some engineering courses. Students that have taken engineering courses and/or have some design experience can apply Deterministic Design with PREP after being briefed on its use, while students without experience in engineering problem solving struggle and are less likely to apply Deterministic Design with PREP as intended. Having some engineering, or design background facilitates the process, because PREP requires individual work to be evaluated by team members; students that have been introduced to engineering problem solving and design processes have less trouble approaching design problems individually than students who have not.

High school students are able to apply PREP, but require guidance in Deterministic Design. Their unguided approach can lead to trial and error being used instead. Trial and error causes the PREP to be inapplicable, since designs cannot be reviewed prior to pursuing. In addition, trial and error leads to an abundance of wasted time and materials. A way to compensate for inexperience in engineering problem solving is to provide multiple choice options to make the students' design process deterministic. Before students decide on strategies, present them with numerous possible strategies. Before students decide on concepts, present them with numerous workable approaches to accomplishing their strategies. Students are stimulated by what has been presented to them, and find it easier to move forward having had a reference point.

College students are able to apply Deterministic Design with PREP soon after being introduced to it. With even more experienced problem solvers and experienced deterministic designers, I have experienced the process being applied even more effectively. The design of the 2004 competition table for 2.007 was completed by students who had taken 2.007 and a junior majoring in physics. For approximately two weeks, the team of five collaborated on a table design without using Deterministic Design with PREP. Without an ordered process, ideas were being developed as a team. As ideas were being presented, many were rejected before having the opportunity to be developed. This led to limited designs and much repeat work. After several unsatisfactory table designs, PREP was applied. The result was an abundance of ideas, healthy discussion, and an agreeable table design in approximately two weeks time.

For best results, students should thus have an understanding of the principles involved in solving assigned design problems and research experience is also helpful. It is also important for students to respect the importance of maintaining schedules. When Deterministic Design with PREP is employed as intended, it should result in an increase in design sophistication and a decrease in design time. Hence, it can be a simple enough process for any team to use, but it does require a modest level of discipline associated with wanting to work with others. PREP facilitates design work in teams (i.e. it is a process to promote collaboration), though PREP itself does not make individuals better designers. Designing deterministically does help individuals become better designers. Table 5-1 lists some pros and cons of using PREP.

Inferred PREP Pros & Cons	
Pros	Makes for efficient teamwork
	Sophistication of designs
	Facilitates learning from peers
	Encompasses Deterministic Design
	Greatly enhanced by related domain knowledge
	Transferable to other disciplines
Cons	Greatly enhanced by related domain knowledge
	Requires a committed team, or demand from a superior/supervisor
	Works best with small teams (3-4 people/team)

Table 5-1: Pros and Cons of using PREP

I have not experienced Deterministic Design with PREP being used by students earlier than ninth grade. My experience with high school students leads me to believe that before high school, students may not have a strong enough background to design deterministically without much guidance. However, I am confident that students are capable of applying PREP prior to high school. Also, experience with high school, college, and experienced designers leads me to conclude that the earlier students learn PREP, the more open they are to peer-review. High school students having learned PREP remain very open to using the practice, while college students require more encouragement to continue practicing PREP. More experienced designers have a tendency to seek review only when progress is declining. I propose the behavior of college students and experienced designers is the result of not wanting to appear incompetent. However, if early in life all students learn the value of peer-review, the practice will eventually become commonplace in college and professional environments.

6 CONCLUSIONS

Deterministic Design with PREP is a sound process for the development of a broad range of new products. Its application in the Second Summer Program has led to three new patents. It is also a favorable process for fostering high levels of team collaboration and particularly with diverse teams. It has helped to welcome underrepresented minorities, women, introverts, and the disabled as part of design teams, by providing an environment where their contributions are not discounted due to inattention and/or aggressive behavior of other team members. PREP is useful in helping identify the domain knowledge of each team member, as the level of detail of each reviewers comments during peer-review is dependent on the reviewers familiarity with material s/he is reviewing. Using PREP, early awareness of domain knowledge helps determine how to later divide work. Deterministic Design with PREP is also transferable to other disciplines such as writing, music, and grading/evaluations.

Freshman and sophomore high school students can begin working in groups using PREP. For this age group, it is helpful to use examples and questioning to guide development. Providing related stimuli helps students develop ideas. For example, before designing a remote control car, have students take apart a remote control car to understand the functional requirements and select design parameters. These students are able to understand weighted selection but require guidance. Generally they need direction in setting criteria that are measurable and guidance in making idea comparisons, so that they thoroughly consider the pros and cons of each idea.

Upperclassman high school and first year college students are capable of applying Deterministic Design with PREP as intended. They should be encouraged to apply fundamentals of math and science to their design work. When they seek assistance, suggestions on where to seek resources may be offered, though it is not necessary to provide examples (i.e. related stimuli). It is good to encourage them to conduct research to learn the background information necessary for developing their ideas. They should be encouraged to thoroughly review work of peers. Many of them are use to thinking competitively, so initially in conducting peer-review, many resist giving their full opinion on how to improve work, fearing that they will not receive deserved credit for their contribution. After conduction peer-review, group discussion for this age group generally runs smoothly. At this point, the team members generally have an idea of what they want to pursue and domain knowledge has been identified during peer-review, so it is easy to decide how to divide workload.

Upperclassmen college students either take to the process, or they do not. Some like working with others and are open to peer-review. These students take well to the process. Some assume peer-review is a waste of time. However, direct observation suggests an unwillingness to give and/or receive feedback to be the dominant reason for students not wanting to conduct or receive peer-review. They may not be comfortable with performance level, or find criticism of peers to be offensive.

The earlier students begin using PREP, the better. Grade school students look for direction more than college students, so it is generally easier to get them to adopt the process. Also, habits learned early later define character. If students learn PREP while in grade school, it will be an accepted/expected process by the time they are in college. It is said that you can teach an old dog new tricks. However, after experiencing the usefulness of the process, college students continued to use it later in life. Even if students do not learn PREP early in life (i.e. high school or before), they can pick it up when they are older.

Deterministic Design with PREP is a sound process for establishing design teams for the creation of new products. Team collaboration was reported to be extremely high. With 100% collaboration being all teammates contributing all of their energy to group work, students reported 76.5% collaboration toward the beginning of projects and 90% collaboration toward the end of projects. Above average satisfaction with the process was also reported. Design results indicate that it helps improve design sophistication for individuals as team (i.e. the whole is greater than the sum of the parts). And 75% of students who learned PREP use it 50% of the time when working with others.

Communication skills are also developed through Deterministic Design with PREP. Since peer-review is conducted without talking, students become effective at written communication. In reviewing the work of others, students become effective at reading other people's work and writing constructive criticism. And group discussion/brainstorming helps students become comfortable with oral communication. This is validated by reports from students of a 93.94% average comfort rating with presenting ideas to rest a team and 86.72% average agreement rating that their ideas are recognized by the rest of a team.

The objective of this work was to develop a deterministic design and teaching process for the creation of new products ranging from books, to music, to consumer products. Deterministic Design with PREP is just that. It is especially useful for diverse teams of designers with members from various cultures, races, genders and personalities, and it is also a favorable process for the disabled. Of student questioned after learning the process, over 45% use PREP 75% of the time and over 75% use PREP at least 50% of the time when working with others. Its application in design programs has led to three issued patents and one pending. The process has been introduced to and adopted in universities in South America and Europe, as well as scores of high schools throughout the US. Deterministic Design with PREP is a sound process for teaching design and for developing new products.

7 FURTHER DEVELOPMENT OF CURRICULUM

Study of designers ranging from high school freshman to professional engineers has provided positive information about levels of peer collaboration throughout development and indicates satisfaction with Deterministic Design with PREP. A proven process in combination with a teamwork practice was used in development of all projects. Significant data was collected about what individual designers and teams are capable of at ordered stages of development. However, there remains the question of how early can design processes be taught. In order to completely explore this area, further understanding of the cognitive factors associated with design at all levels is crucial.

Some people excel at design, while others do not. There are many bright problem solvers who believe they are incapable of creative thinking (i.e. approaching problems in a way that produces innovative solutions). Can creative thinking be taught and if so, what teaching techniques are available? In pursuit of creating methods for designing designers, studying the practices of experienced designers is a good start. It is also beneficial to study novice designers and their approaches as they attempt to solve complex design problems. Collaboration with cognitive scientists, would offer insight as to what design behaviors are shared by novice and experienced designers. Such knowledge may result in a plethora of individuals with basic design skills and consequently an increase in the overall creativity of the public. Further understanding of how exceptional design engineers think will not only increase their number, but may also provide a framework for further advancements in the area of tools for design synthesis.

In further developing the curriculum, broader use is to be pursued as well. In addition to the MIT courses and special programs discussed throughout this thesis, Deterministic Design with PREP is also being introduced to the Lemelson-MIT InvenTeams[1] program as an invention development process. A manual has been prepared for distribution to eighteen current InvenTeams and all other high schools nationwide applying for InvenTeams grants. Also, the web portal designed with the support of the MIT/Microsoft Alliance is to be further developed to assist teams in using PREP. For a number of years I presented the process to InvenTeams teachers as

1. http://web.mit.edu/inventeams/

part of a teachers workshop hosted by Lemelson-MIT. A number of teachers reported they have practiced aspects of the process with their students and noted how it helped get the female students more involved in the projects.

As the process is implemented in US high schools and universities in South America and Europe, effectiveness of its application away from MIT can be further explored. In April of 2006, the process was adopted by the mechanical engineering department at la Universidad de Castilla-la Mancha in Ciudad Real, Spain. The students in a design class were assigned the task of using Deterministic Design with PREP to develop machine designs for excavating a mine. Results will be shared upon completion of the projects. Feedback from partnering schools will provide information on the level of difficulty of expanding the use of Deterministic Design with PREP. Depending on the level of difficulty, further expansion and/or further development of the curriculum will result.

APPENDIX A: SECOND SUMMER PROGRAM STUDENTS SURVEY

Second Summer Program Students Survey

Hello! We appreciate your participation in the MIT Second Summer Program. In an effort to evaluate how the course influenced the academic and/or professional development of students involved, we have compiled a survey. Your participation in helping us evaluate the course by completing the survey is voluntary though much appreciated. You may decline to answer any or all questions and you may decline further participation, at any time, without adverse consequences. Confidentiality and/or anonymity are assured. Thank you!

Deterministic Design with PREP

The purpose of this survey is to evaluate the effectiveness of the Deterministic Design Process as it relates to collaboration, time management and comfort in idea sharing.

Deterministic Design is a design process with the following stages of development: 1) Functional Requirements, 2) Design Parameters, 3) Analysis, 4) References, 5) Risks, and 6) Counter-Measures.

PREP, or the Peer-Review Evaluation Process, occurs between each stage of the Deterministic Design process and is made up of the following three phases: 1) Individual Thought, 2) Peer-Review (without discussion), and 3) Group Discussion/Selection

Appendix A Figure 1: Second Summer Deterministic Design with PREP Survey, 2001-2006, page 1

1. Did your team use Deterministic Design with PREP to complete your project? If no, please briefly explain the process your team used.

2. How many hours per day average did your team meet?
a. Toward the beginning
b. Toward the end

3. How many hours per day average did you team spend in the machine shop?
a. Toward the beginning
b. Toward the end

4. How many hours per day average did you spend independently problem solving and/or designing?
a. Toward the beginning
b. Toward the end

5. How many hours per day average did you spend independently in the machine shop?
a. Toward the beginning
b. Toward the end

6. How would you rate your team's overall collaboration?
a. Toward the beginning
100% ☐ 75% ☐ 50% ☐ 25% ☐ None ☐
b. Toward the end
100% ☐ 75% ☐ 50% ☐ 25% ☐ None ☐

7. Did the extent of team collaboration have an impact on your performance?
a. Toward the beginning
Absolutely 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ Not At All
b. Toward the end
Absolutely 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ Not At All

8. How would you rate your personal teamwork effort?
a. Toward the beginning
100% ☐ 75% ☐ 50% ☐ 25% ☐ None ☐
b. Toward the end
100% ☐ 75% ☐ 50% ☐ 25% ☐ None ☐

9. How comfortable did you feel presenting your ideas to the rest of the team?
a. Toward the beginning
100% ☐ 75% ☐ 50% ☐ 25% ☐ None ☐

Appendix A Figure 2: Second Summer Deterministic Design with PREP Survey, 2001-2006, page 2

b. Toward the end

100% ☐ 75% ☐ 50% ☐ 25% ☐ None ☐

10. Do you agree your contributions were recognized by your teammates?

a. Toward the beginning

100% ☐ 75% ☐ 50% ☐ 25% ☐ None ☐

b. Toward the end

100% ☐ 75% ☐ 50% ☐ 25% ☐ None ☐

11. Do you agree your Second Summer Program experience prepared you for a summer internship?

Strongly Agree 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ Strongly Disagree

12. Do you agree your Second Summer Program experience helped you become a better student?

Strongly Agree 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ Strongly Disagree

13. How satisfied were you with the course?

Very Unsatisfied 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ Very Satisfied

14. Since completion of the Second Summer Program, how often do you apply PREP phases 1) Individual Thought, 2) Peer-Review, and 3) Group Discussion in your work with others?

100% ☐ 75% ☐ 50% ☐ 25% ☐ None ☐

Appendix A Figure 3: Second Summer Deterministic Design with PREP Survey, 2001-2006, page 3

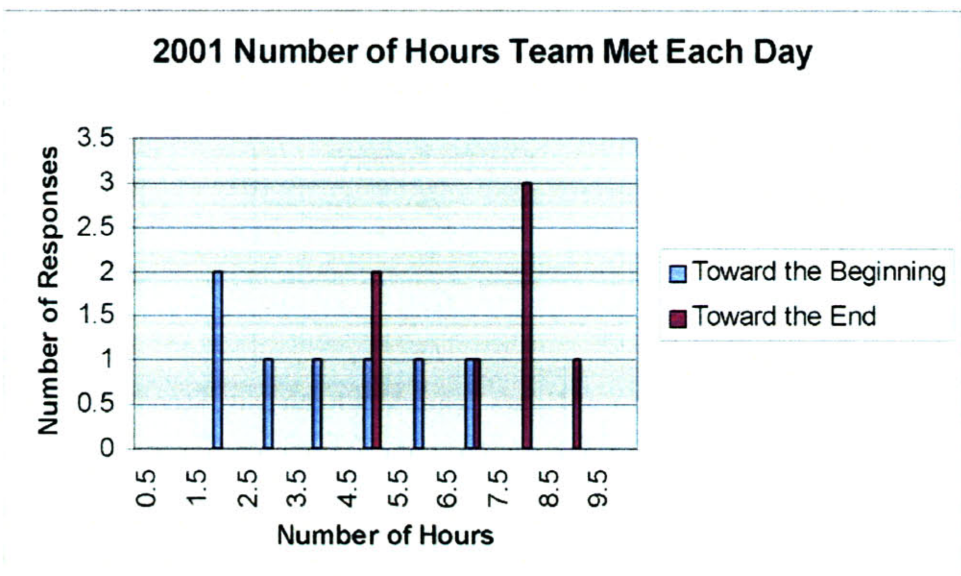
APPENDIX B: SECOND SUMMER PROGRAM SURVEY RESPONSES

1.1 Background

All surveys were completed three months after the conclusion of the 2006 Second Summer Program. Students from years 2001-2002 were graduates of MIT when they completed the survey and students from 2003, 2004, 2005 and 2006 were MIT seniors, juniors, sophomores, and freshmen respectively.

1.2 Number of Hours Team Met Each Day

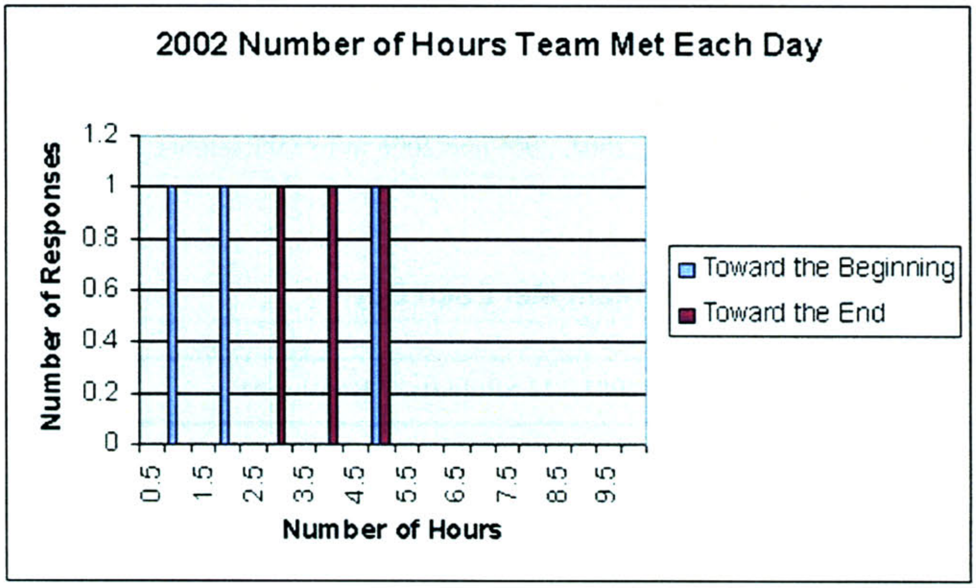
Year 2001 - 42 Students, 7 Responses



	Toward the Beginning	Toward the End
2001 Average	4.14	7.14
2001 Unbiased Standard of Deviation	1.95	1.57
2001-2006 Average	2.63	5.52
2001-2006 Unbiased Standard of Deviation	1.65	2.34

Appendix B Figure 1: Number of Hours Team Met Each Day, Second Summer 2001

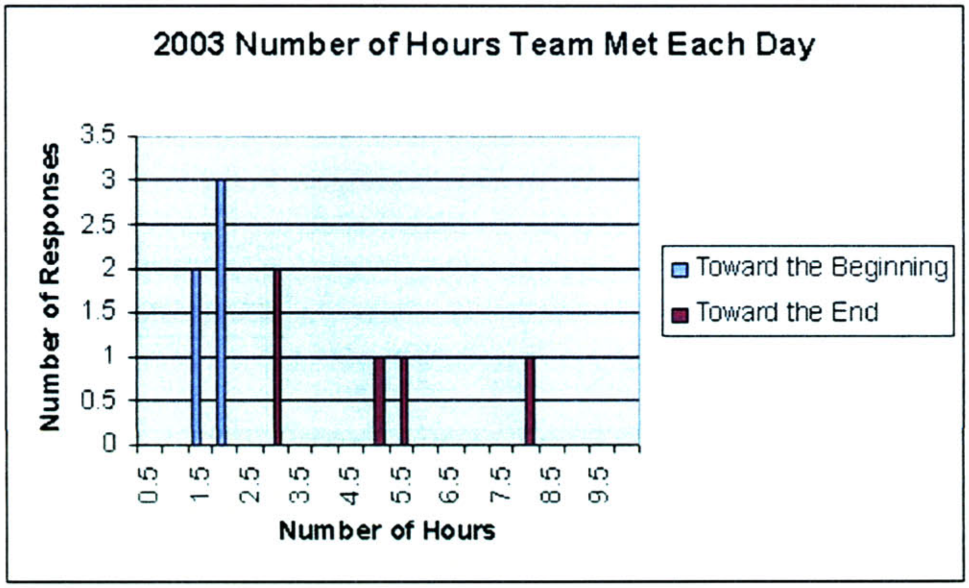
Year 2002 - 27 Students, 3 Responses



	Toward the Beginning	Toward the End
2002 Average	2.67	4.00
2002 Unbiased Standard of Deviation	2.08	1.00
2001-2006 Average	2.63	5.52
2001-2006 Unbiased Standard of Deviation	1.65	2.34

Appendix B Figure 2: Number of Hours Team Met Each Day, Second Summer 2002

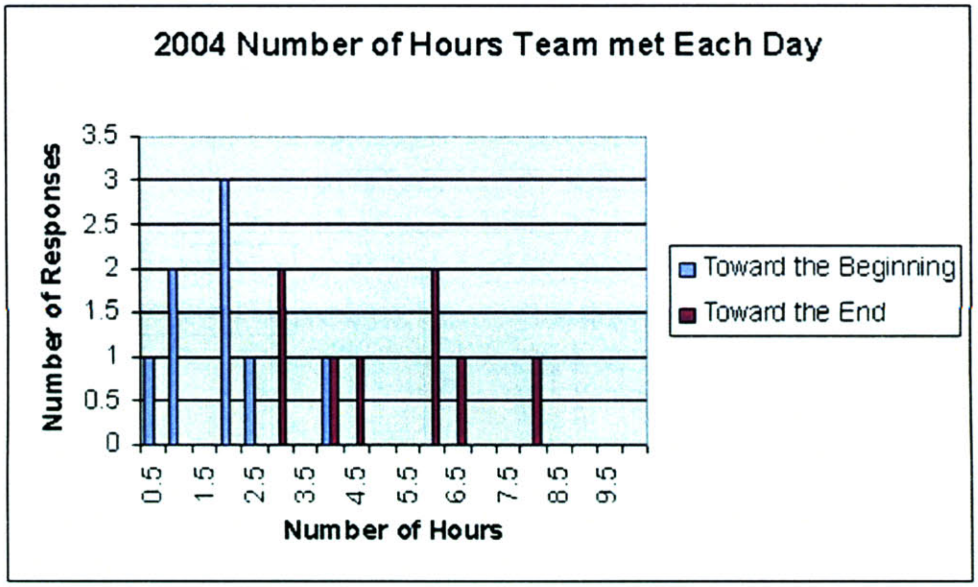
Year 2003 - 28 Students, 5 Responses



	Toward the Beginning	Toward the End
2003 Average	1.80	4.90
2003 Unbiased Standard of Deviation	0.27	2.07
2001-2006 Average	2.63	5.52
2001-2006 Unbiased Standard of Deviation	1.65	2.34

Appendix B Figure 3: Number of Hours Team Met Each Day, Second Summer 2003

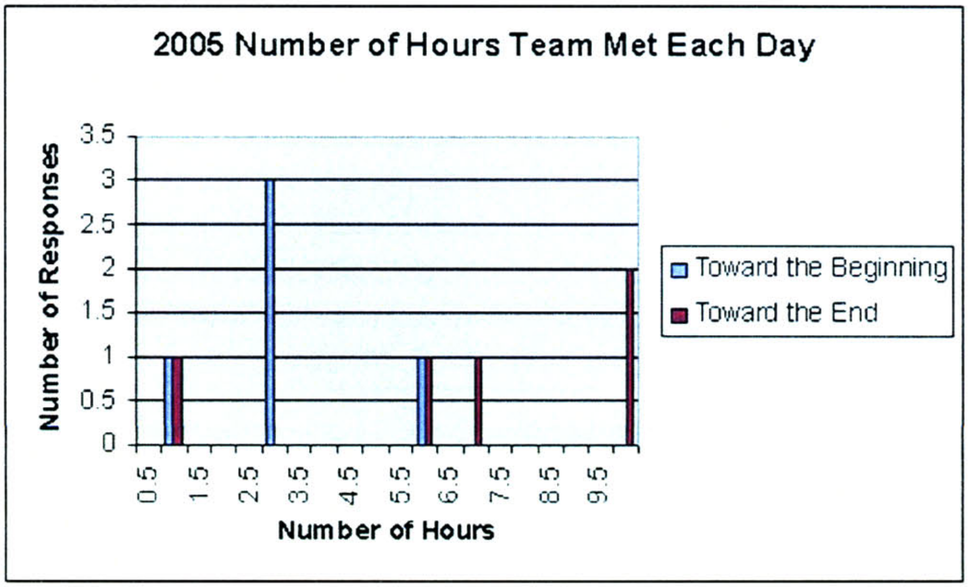
Year 2004 - 29 Students, 8 Responses



	Toward the Beginning	Toward the End
2004 Average	1.88	5.13
2004 Unbiased Standard of Deviation	1.09	1.79
2001-2006 Average	2.63	5.52
2001-2006 Unbiased Standard of Deviation	1.65	2.34

Appendix B Figure 4: Number of Hours Team Met Each Day, Second Summer 2004

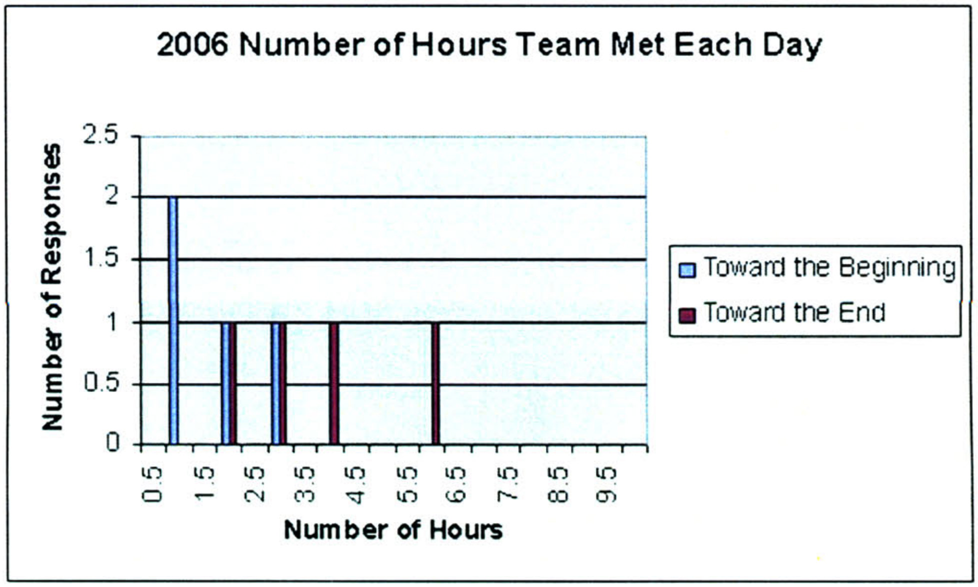
Year 2005 - 19 Students, 5 Responses



	Toward the Beginning	Toward the End
2005 Average	3.20	6.80
2005 Unbiased Standard of Deviation	1.79	3.70
2001-2006 Average	2.63	5.52
2001-2006 Unbiased Standard of Deviation	1.65	2.34

Appendix B Figure 5: Number of Hours Team Met Each Day, Second Summer 2005

Year 2006 - 10 Students, 4 Responses

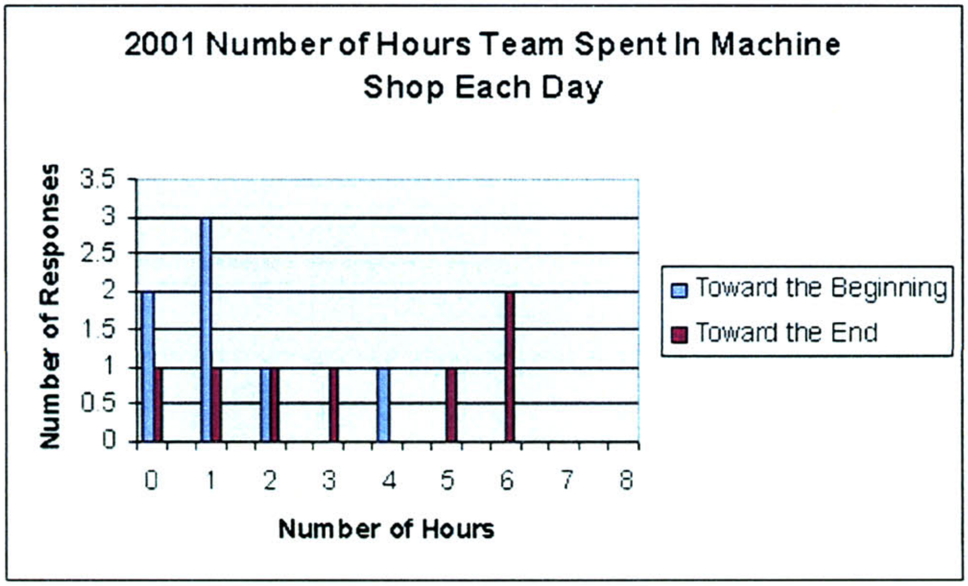


	Toward the Beginning	Toward the End
2006 Average	1.75	3.75
2006 Unbiased Standard of Deviation	0.96	1.71
2001-2006 Average	2.63	5.52
2001-2006 Unbiased Standard of Deviation	1.65	2.34

Appendix B Figure 6: Number of Hours Team Met Each Day, Second Summer 2006

1.3 Number of Hours Team Spent In Machine Shop Each Day

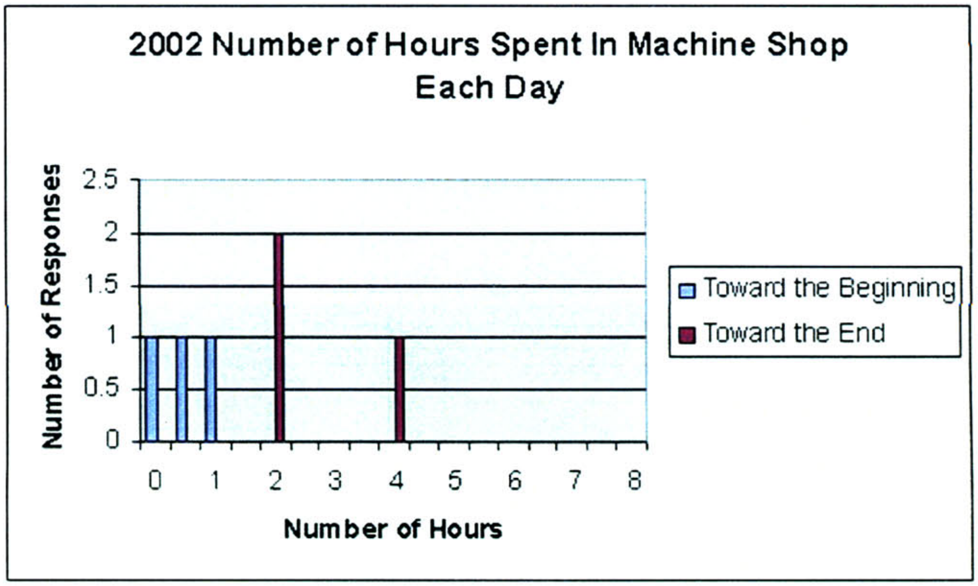
Year 2001 - 42 Students, 7 Responses



	Toward the Beginning	Toward the End
2001 Average	1.29	3.29
2001 Unbiased Standard of Deviation	1.38	2.43
2001-2006 Average	0.84	3.44
2001-2006 Unbiased Standard of Deviation	0.87	1.90

Appendix B Figure 7: Number of Hours Team Spent In Machine Shop Each Day, Second Summer 2001

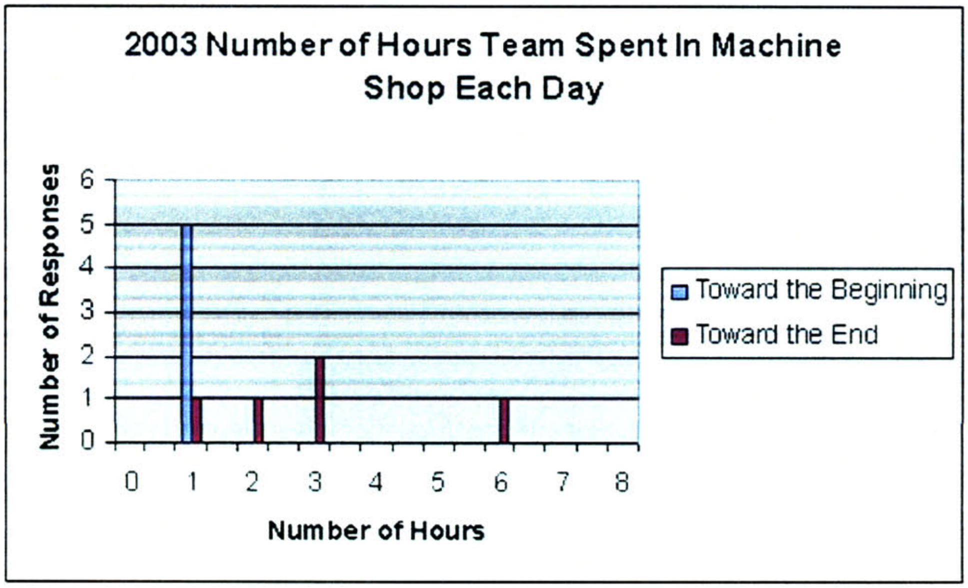
Year 2002 - 27 Students, 3 Responses



	Toward the Beginning	Toward the End
2002 Average	0.50	2.67
2002 Unbiased Standard of Deviation	0.50	1.15
2001-2006 Average	0.84	3.44
2001-2006 Unbiased Standard of Deviation	0.87	1.90

Appendix B Figure 8: Number of Hours Team Spent In Machine Shop Each Day, Second Summer 2002

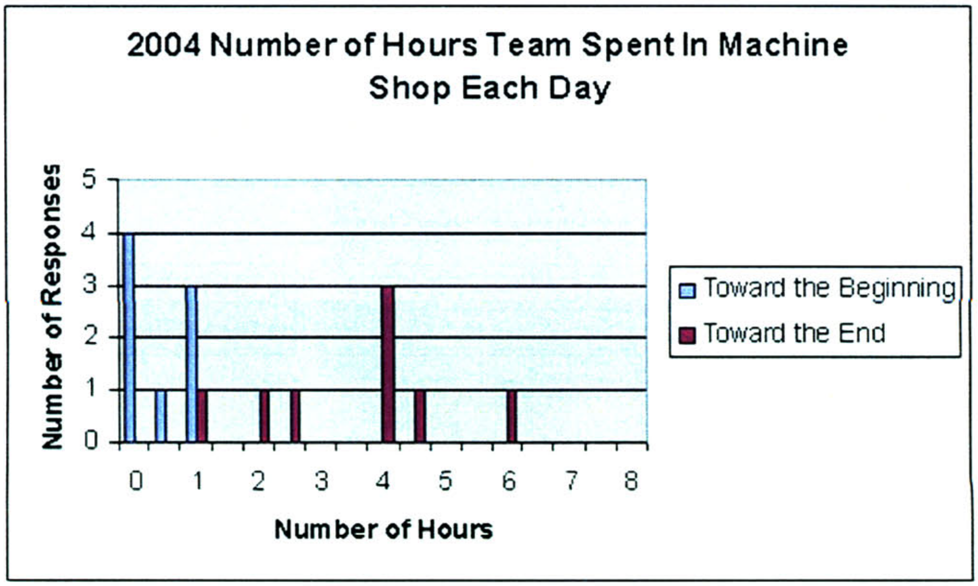
Year 2003 - 28 Students, 5 Responses



	Toward the Beginning	Toward the End
2003 Average	1.00	3.00
2003 Unbiased Standard of Deviation	0.00	1.87
2001-2006 Average	0.84	3.44
2001-2006 Unbiased Standard of Deviation	0.87	1.90

Appendix B Figure 9: Number of Hours Team Spent In Machine Shop Each Day, Second Summer 2003

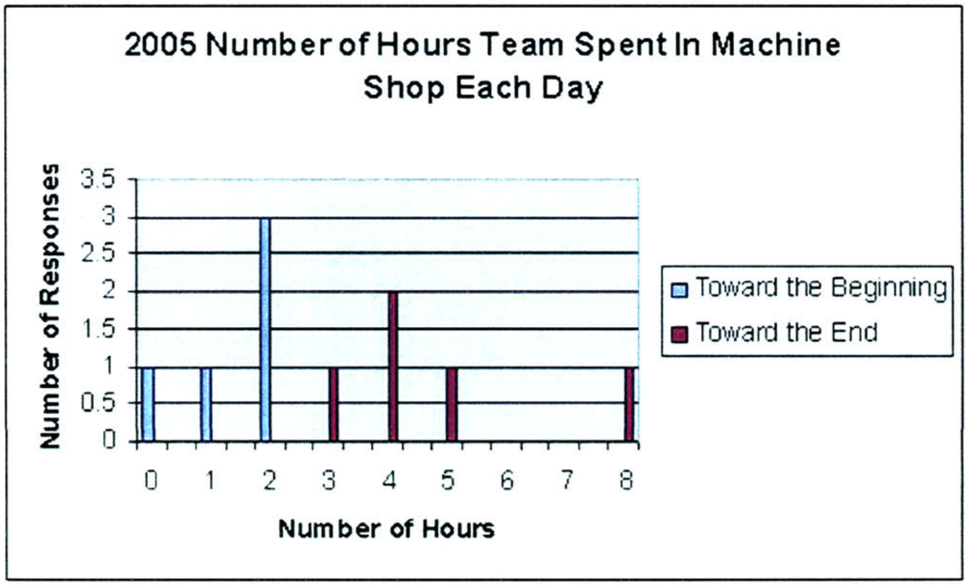
Year 2004 - 29 Students, 8 Responses



	Toward the Beginning	Toward the End
2004 Average	0.44	3.50
2004 Unbiased Standard of Deviation	0.50	1.58
2001-2006 Average	0.84	3.44
2001-2006 Unbiased Standard of Deviation	0.87	1.90

Appendix B Figure 10: Number of Hours Team Spent In Machine Shop Each Day, Second Summer 2004

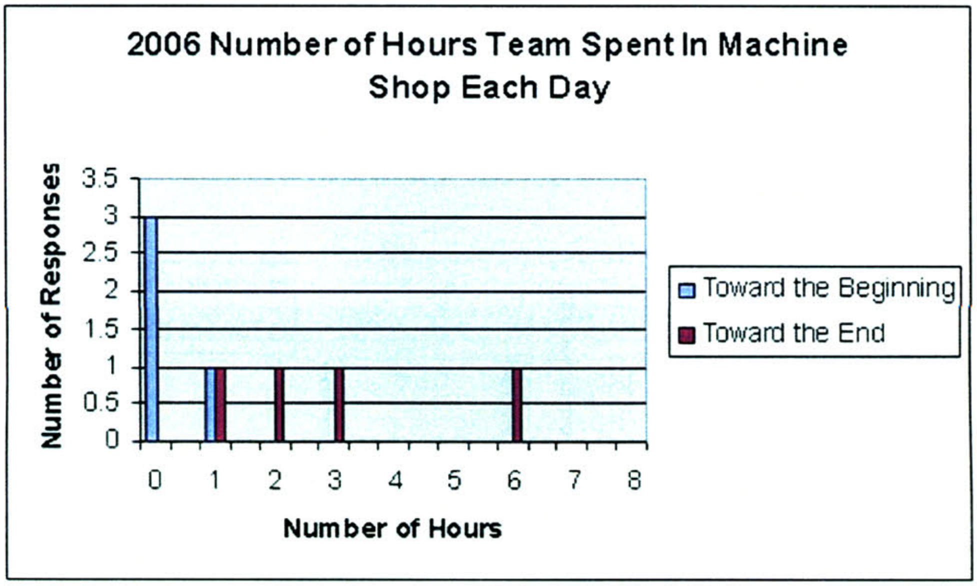
Year 2005 - 19 Students, 5 Responses



	Toward the Beginning	Toward the End
2005 Average	1.40	4.80
2005 Unbiased Standard of Deviation	0.89	1.92
2001-2006 Average	0.84	3.44
2001-2006 Unbiased Standard of Deviation	0.87	1.90

Appendix B Figure 11: Number of Hours Team Spent In Machine Shop Each Day, Second Summer 2005

Year 2006 - 10 Students, 4 Responses

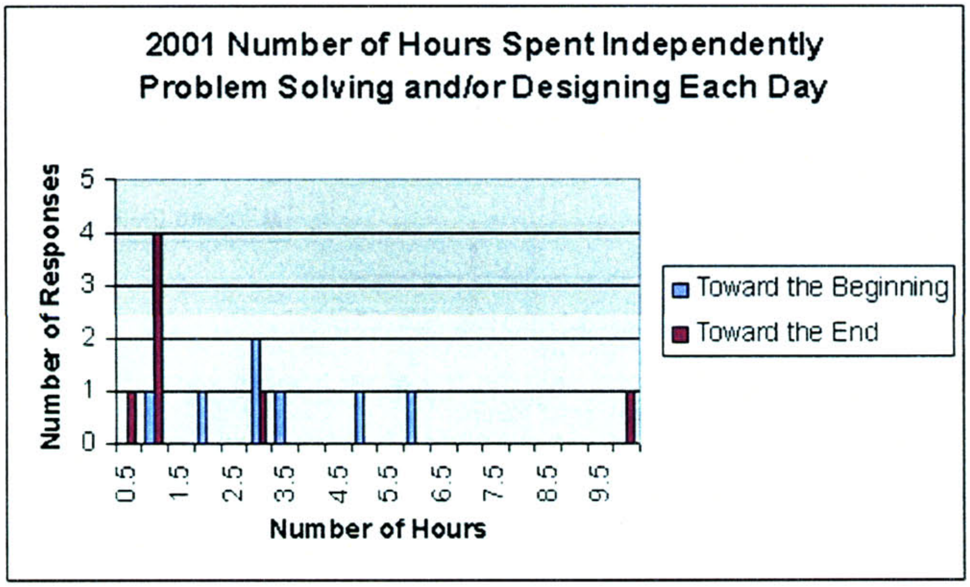


	Toward the Beginning	Toward the End
2006 Average	0.25	3.00
2006 Unbiased Standard of Deviation	0.50	2.16
2001-2006 Average	0.84	3.44
2001-2006 Unbiased Standard of Deviation	0.87	1.90

Appendix B Figure 12: Number of Hours Team Spent In Machine Shop Each Day, Second Summer 2006

1.4 Number of Hours Spent Independently Problem Solving and/or Designing Each Day

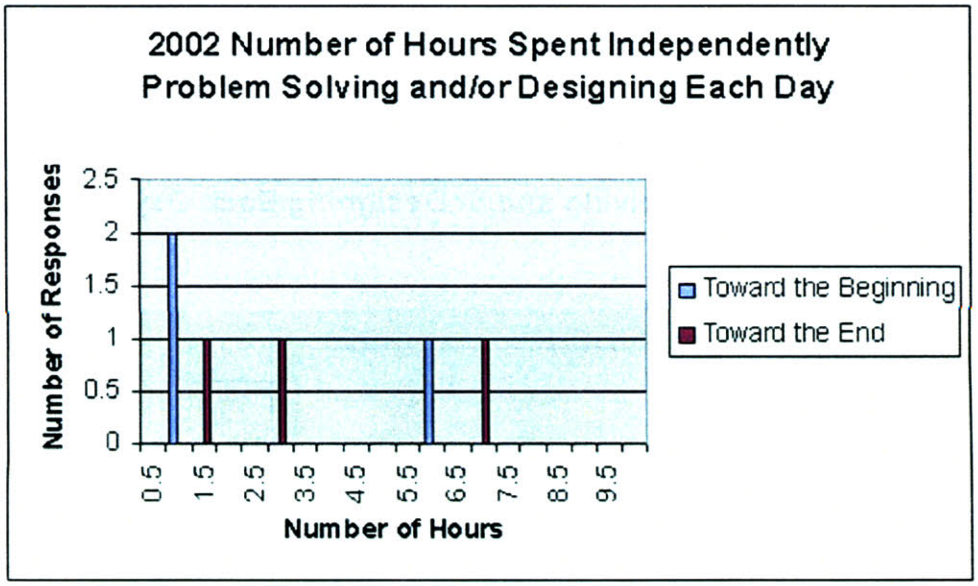
Year 2001 - 42 Students, 7 Responses



	Toward the Beginning	Toward the End
2001 Average	3.36	2.43
2001 Unbiased Standard of Deviation	1.70	3.46
2001-2006 Average	2.05	2.25
2001-2006 Unbiased Standard of Deviation	1.44	2.17

Appendix B Figure 13: Number of Hours Spent Independently Problem Solving and/or Designing Each Day, Second Summer 2001

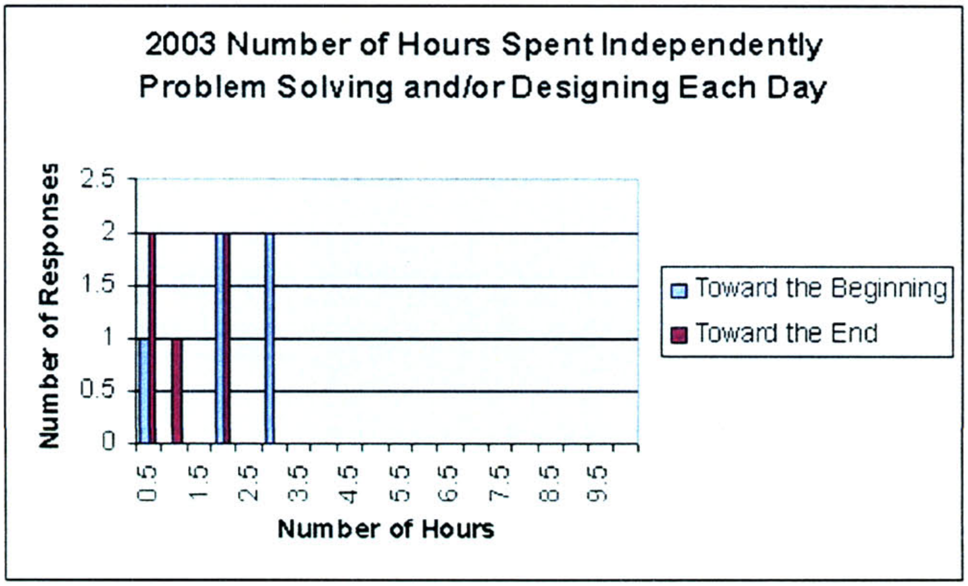
Year 2002 - 27 Students, 3 Responses



	Toward the Beginning	Toward the End
2002 Average	2.67	3.83
2002 Unbiased Standard of Deviation	2.89	2.84
2001-2006 Average	2.05	2.25
2001-2006 Unbiased Standard of Deviation	1.44	2.17

Appendix B Figure 14: Number of Hours Spent Independently Problem Solving and/or Designing Each Day, Second Summer 2002

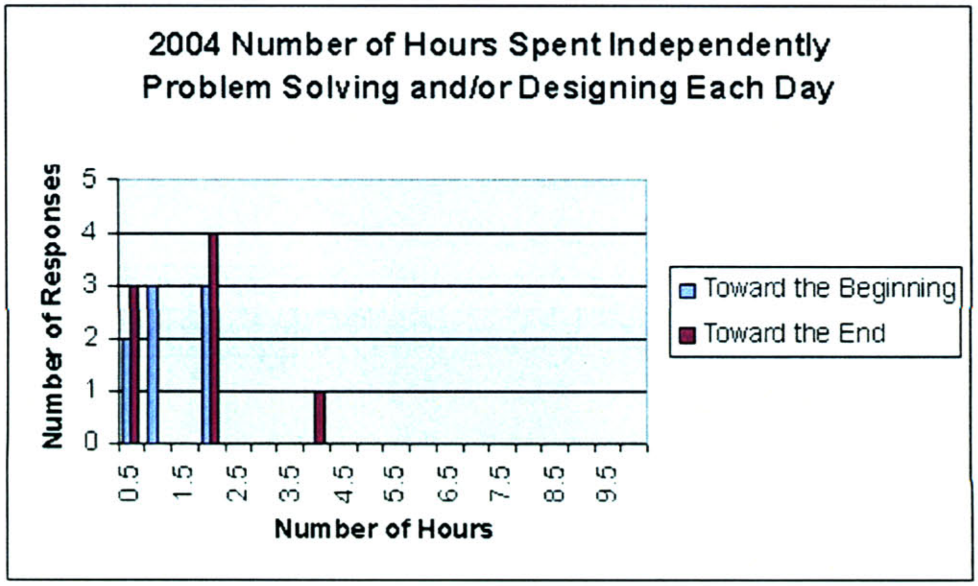
Year 2003 - 28 Students, 5 Responses



	Toward the Beginning	Toward the End
2003 Average	2.10	1.20
2003 Unbiased Standard of Deviation	1.02	0.76
2001-2006 Average	2.05	2.25
2001-2006 Unbiased Standard of Deviation	1.44	2.17

Appendix B Figure 15: Number of Hours Spent Independently Problem Solving and/or Designing Each Day, Second Summer 2003

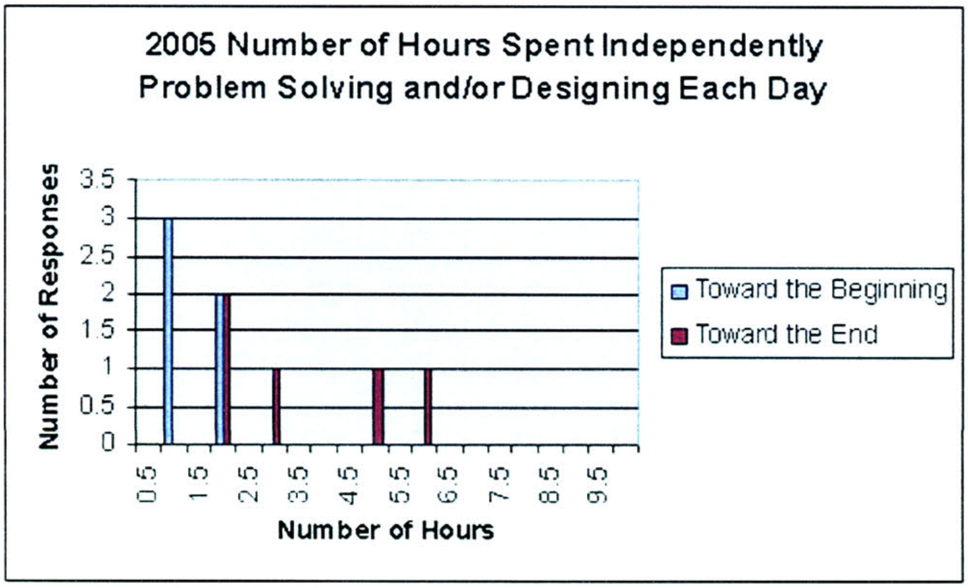
Year 2004 - 29 Students, 8 Responses



	Toward the Beginning	Toward the End
2004 Average	1.25	1.56
2004 Unbiased Standard of Deviation	0.65	1.35
2001-2006 Average	2.05	2.25
2001-2006 Unbiased Standard of Deviation	1.44	2.17

Appendix B Figure 16: Number of Hours Spent Independently Problem Solving and/or Designing Each Day, Second Summer 2004

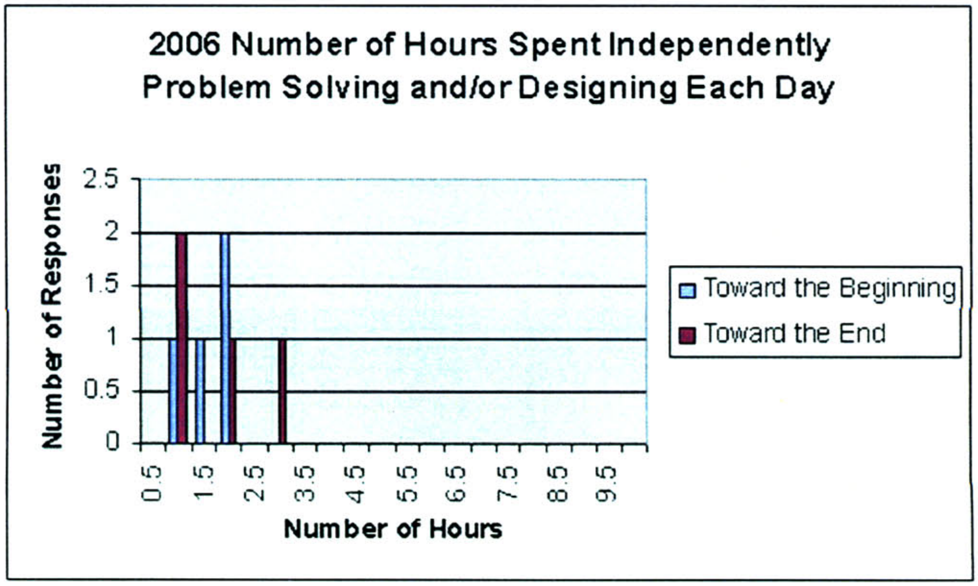
Year 2005 - 19 Students, 5 Responses



	Toward the Beginning	Toward the End
2005 Average	1.40	3.60
2005 Unbiased Standard of Deviation	0.55	1.82
2001-2006 Average	2.05	2.25
2001-2006 Unbiased Standard of Deviation	1.44	2.17

Appendix B Figure 17: Number of Hours Spent Independently Problem Solving and/or Designing Each Day, Second Summer 2005

Year 2006 - 10 Students, 4 Responses

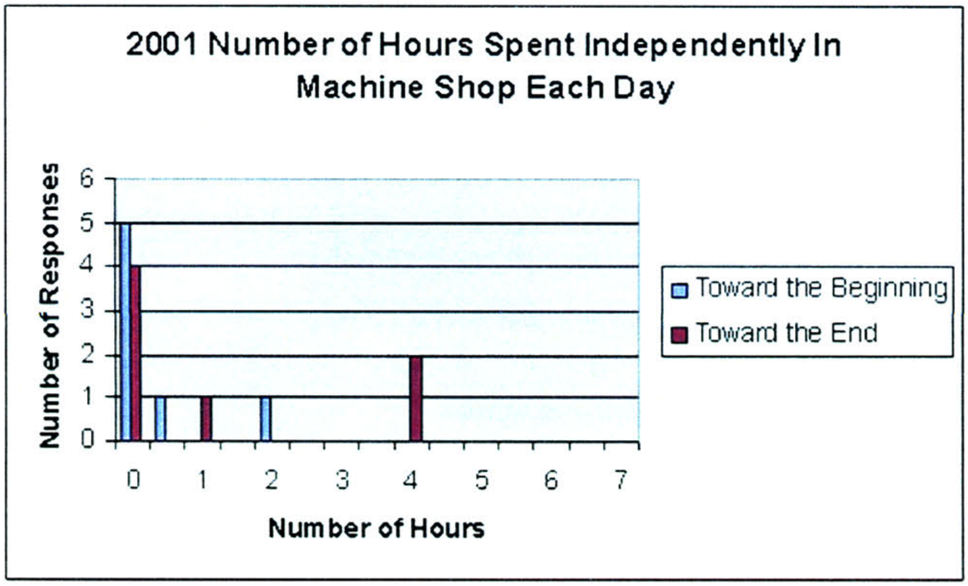


	Toward the Beginning	Toward the End
2006 Average	1.63	1.75
2006 Unbiased Standard of Deviation	0.48	0.96
2001-2006 Average	2.05	2.25
2001-2006 Unbiased Standard of Deviation	1.44	2.17

Appendix B Figure 18: Number of Hours Spent Independently Problem Solving and/or Designing Each Day, Second Summer 2006

1.5 Number of Hours Spent Independently in Machine Shop Each Day

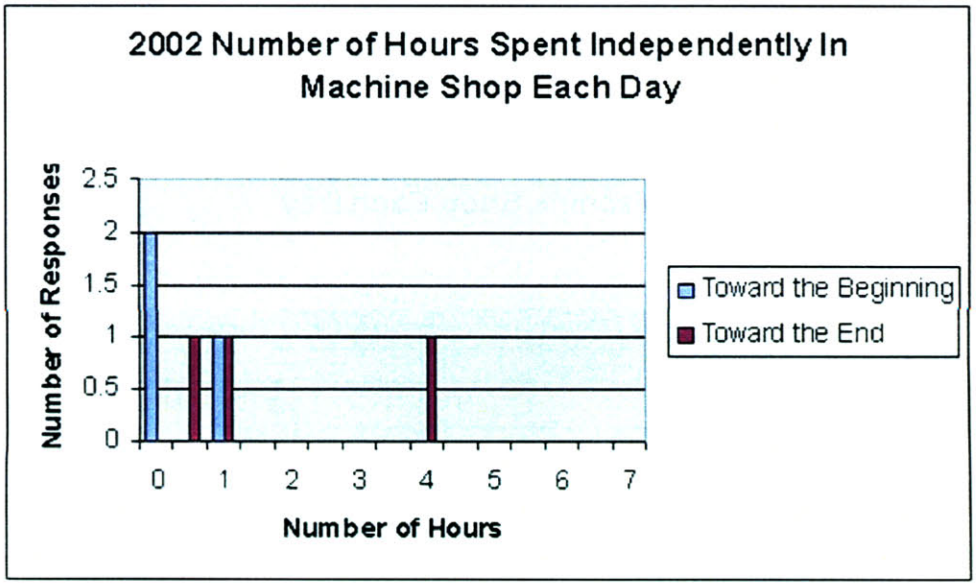
Year 2001 - 42 Students, 7 Responses



	Toward the Beginning	Toward the End
2001 Average	0.36	1.29
2001 Unbiased Standard of Deviation	0.75	1.89
2001-2006 Average	0.23	0.48
2001-2006 Unbiased Standard of Deviation	1.60	2.05

Appendix B Figure 19: Number of Hours Spent Independently In Machine Shop Each Day, Second Summer 2001

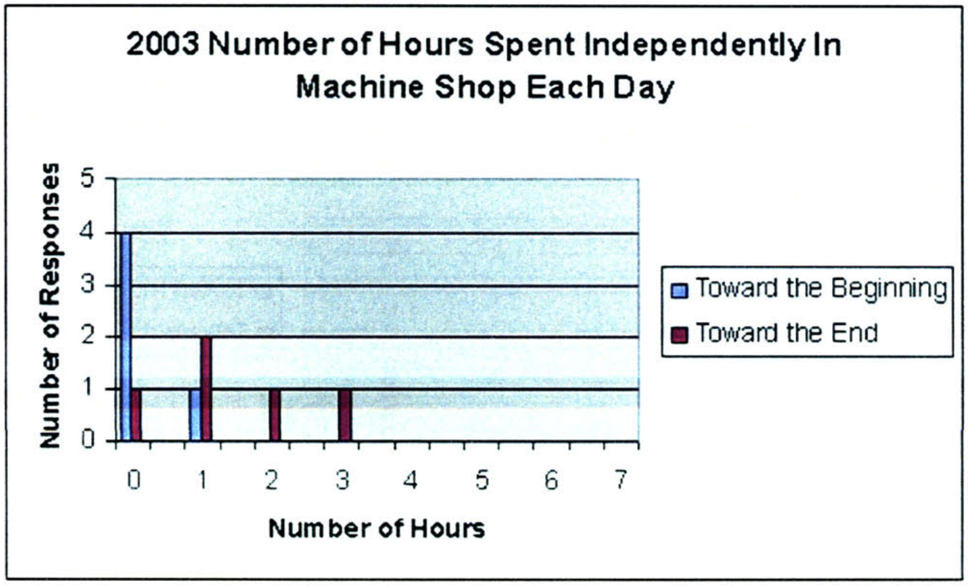
Year 2002 - 27 Students, 3 Responses



	Toward the Beginning	Toward the End
2002 Average	0.33	1.83
2002 Unbiased Standard of Deviation	0.58	1.89
2001-2006 Average	0.23	0.48
2001-2006 Unbiased Standard of Deviation	1.60	2.05

Appendix B Figure 20: Number of Hours Spent Independently In Machine Shop Each Day, Second Summer 2002

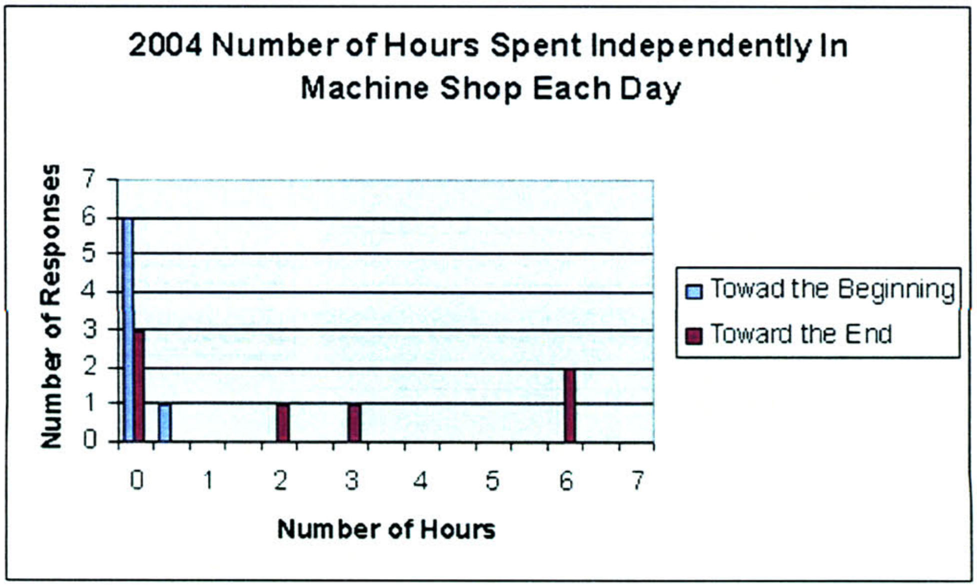
Year 2003 - 28 Students, 5 Responses



	Toward the Beginning	Toward the End
2003 Average	0.20	1.40
2003 Unbiased Standard of Deviation	0.45	1.14
2001-2006 Average	0.23	0.48
2001-2006 Unbiased Standard of Deviation	1.60	2.05

Appendix B Figure 21: Number of Hours Spent Independently In Machine Shop Each Day, Second Summer 2003

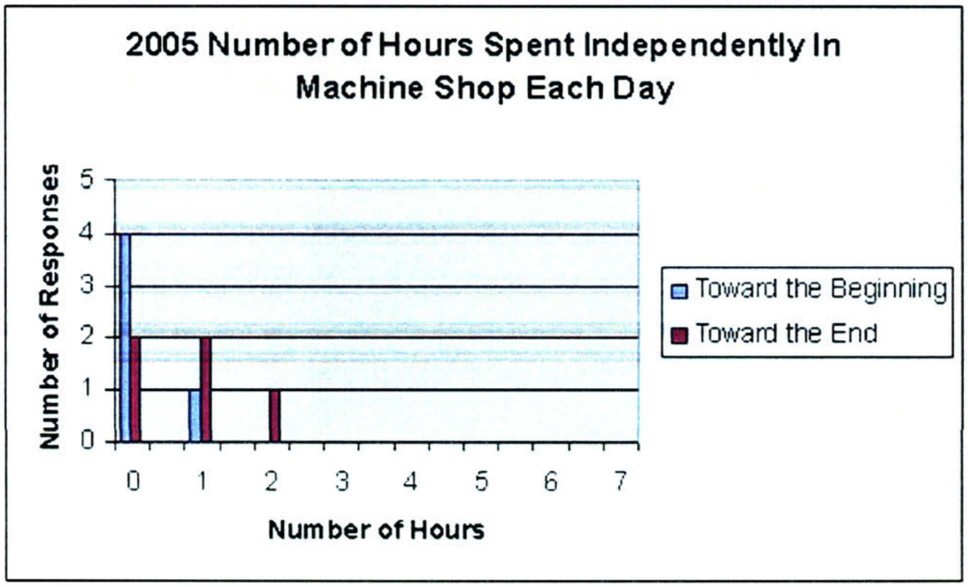
Year 2004 - 29 Students, 7 Responses



	Toward the Beginning	Toward the End
2004 Average	0.07	2.43
2004 Unbiased Standard of Deviation	0.19	2.70
2001-2006 Average	0.23	0.48
2001-2006 Unbiased Standard of Deviation	1.60	2.05

Appendix B Figure 22: Number of Hours Spent Independently In Machine Shop Each Day, Second Summer 2004

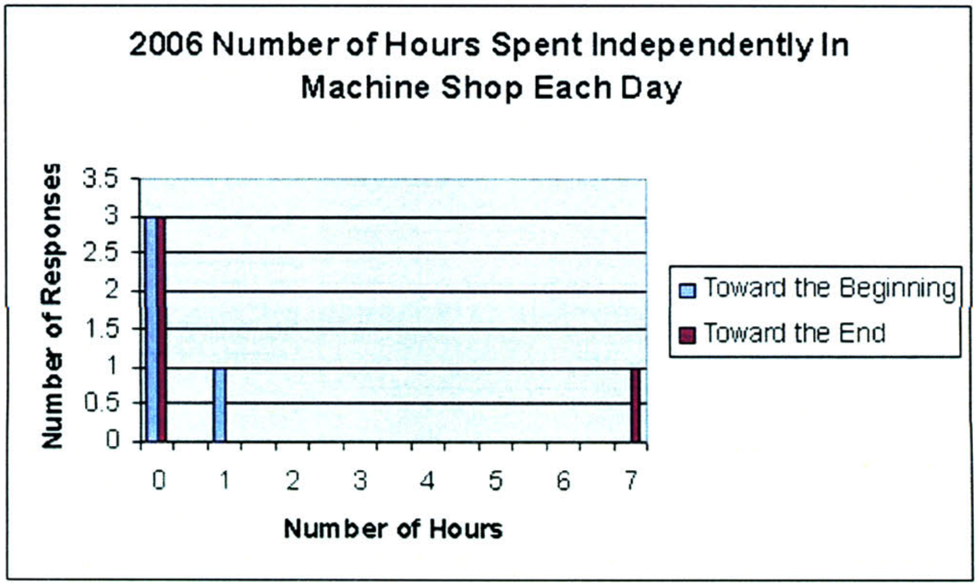
Year 2005 - 19 Students, 5 Responses



	Toward the Beginning	Toward the End
2005 Average	0.20	0.80
2005 Unbiased Standard of Deviation	0.45	0.84
2001-2006 Average	0.23	0.48
2001-2006 Unbiased Standard of Deviation	1.60	2.05

Appendix B Figure 23: Number of Hours Spent Independently In Machine Shop Each Day, Second Summer 2005

Year 2006 - 10 Students, 4 Responses

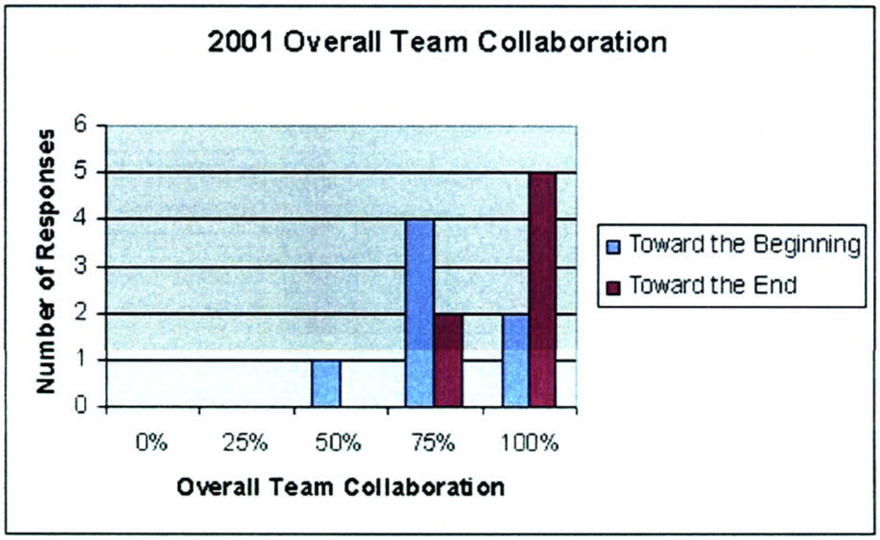


	Toward the Beginning	Toward the End
2006 Average	0.25	1.75
2006 Unbiased Standard of Deviation	0.50	3.50
2001-2006 Average	0.23	0.48
2001-2006 Unbiased Standard of Deviation	1.60	2.05

Appendix B Figure 24: Number of Hours Spent Independently In Machine Shop Each Day, Second Summer 2006

1.6 Overall Team Collaboration

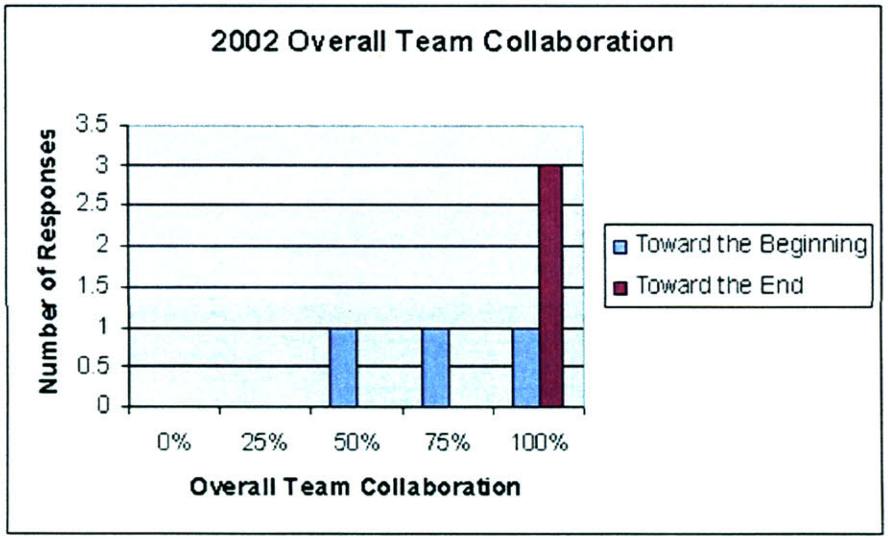
Year 2001 - 42 Students, 7 Responses



	Toward the Beginning	Toward the End
2001 Average	78.57%	92.86%
2001 Unbiased Standard of Deviation	17.25%	12.20%
2001-2006 Average	76.52%	90.15%
2001-2006 Unbiased Standard of Deviation	21.60%	15.23%

Appendix B Figure 25: Overall Team Collaboration, Second Summer 2001

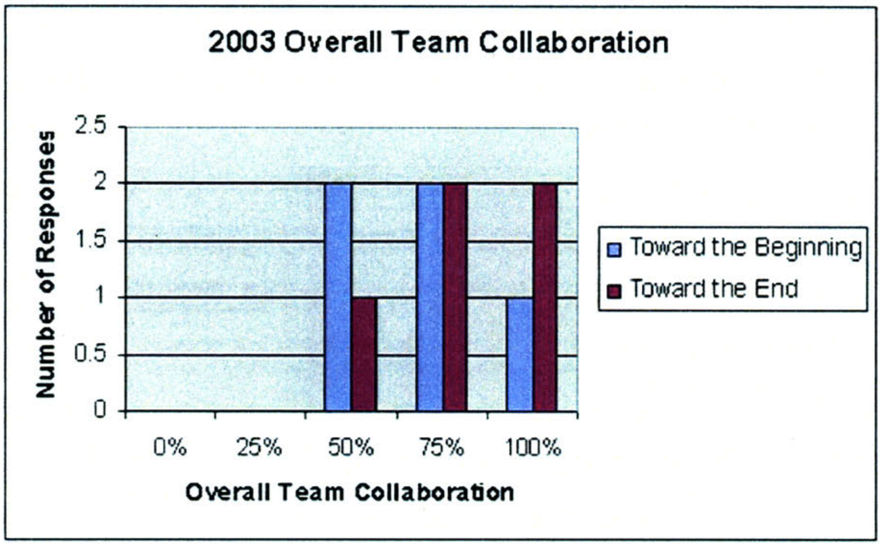
Year 2002 - 27 Students, 3 Responses



	Toward the Beginning	Toward the End
2002 Average	75.00%	100.00%
2002 Unbiased Standard of Deviation	25.00%	0.00%
2001-2006 Average	76.52%	90.15%
2001-2006 Unbiased Standard of Deviation	21.60%	15.23%

Appendix B Figure 26: Overall Team Collaboration, Second Summer 2002

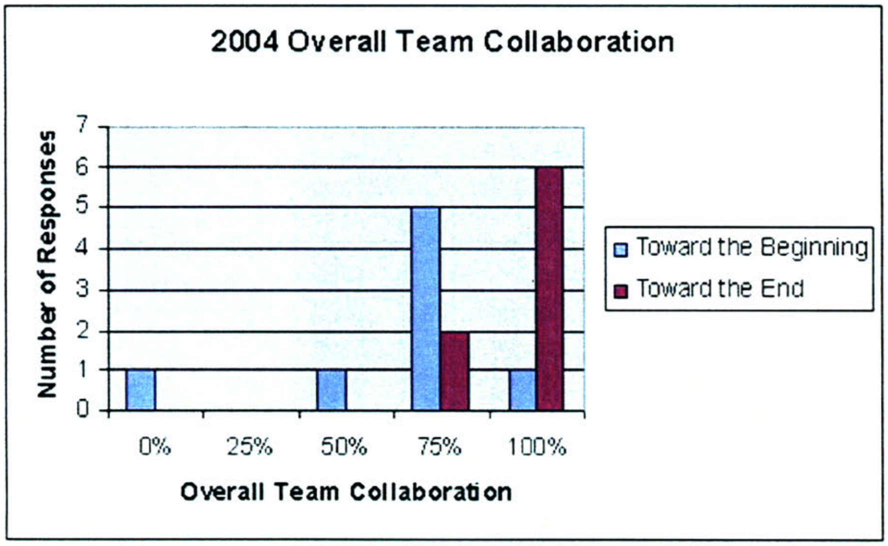
Year 2003 - 28 Students, 5 Responses



	Toward the Beginning	Toward the End
2003 Average	70.83%	79.17%
2003 Unbiased Standard of Deviation	18.82%	18.82%
2001-2006 Average	76.52%	90.15%
2001-2006 Unbiased Standard of Deviation	21.60%	15.23%

Appendix B Figure 27: Overall Team Collaboration, Second Summer 2003

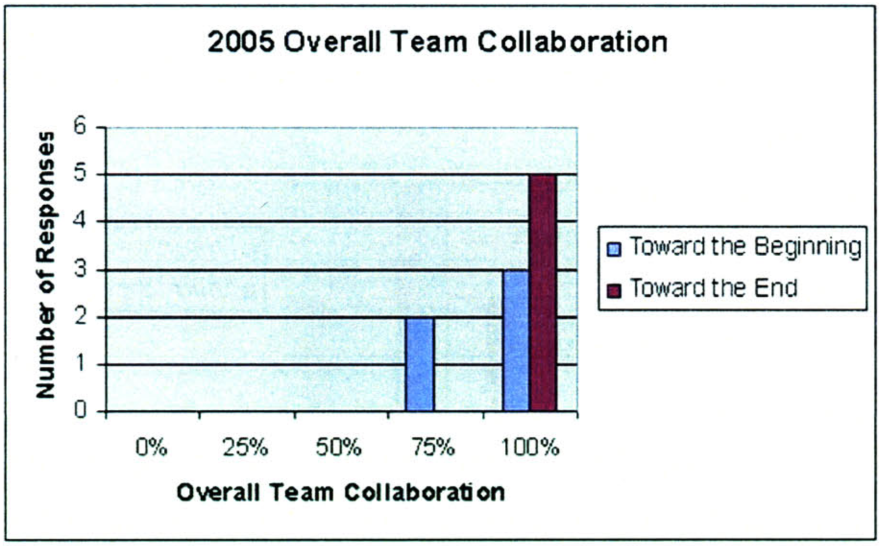
Year 2004 - 29 Students, 8 Responses



	Toward the Beginning	Toward the End
2004 Average	65.63%	93.75%
2004 Unbiased Standard of Deviation	29.69%	11.57%
2001-2006 Average	76.52%	90.15%
2001-2006 Unbiased Standard of Deviation	21.60%	15.23%

Appendix B Figure 28: Overall Team Collaboration, Second Summer 2004

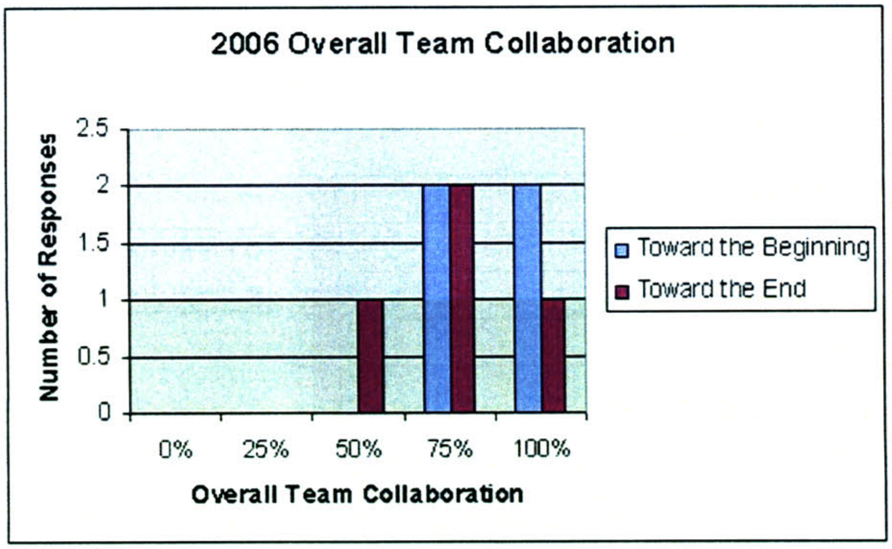
Year 2005 - 19 Students, 5 Responses



	Toward the Beginning	Toward the End
2005 Average	90.00%	100.00%
2005 Unbiased Standard of Deviation	13.69%	0.00%
2001-2006 Average	76.52%	90.15%
2001-2006 Unbiased Standard of Deviation	21.60%	15.23%

Appendix B Figure 29: Overall Team Collaboration, Second Summer 2005

Year 2006 - 10 Students, 4 Responses

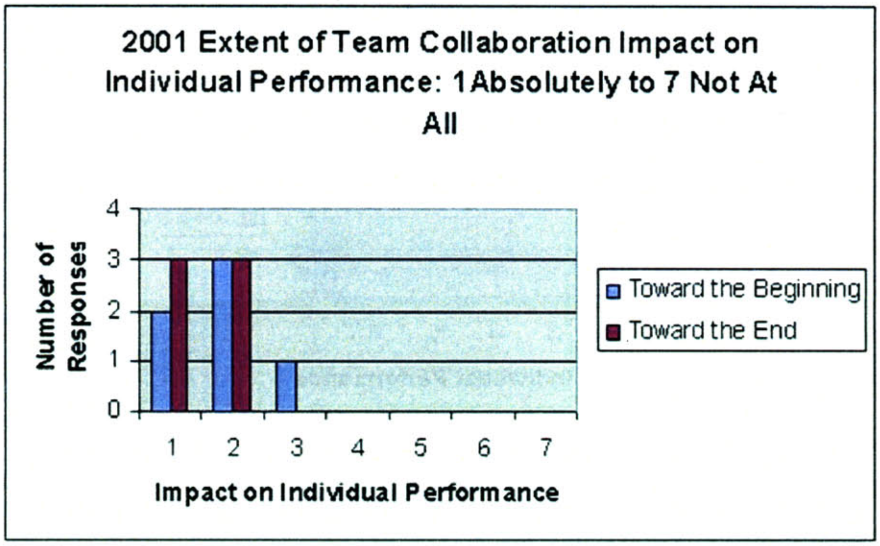


	Toward the Beginning	Toward the End
2006 Average	87.50%	75.00%
2006 Unbiased Standard of Deviation	14.43%	20.41%
2001-2006 Average	76.52%	90.15%
2001-2006 Unbiased Standard of Deviation	21.60%	15.23%

Appendix B Figure 30: Overall Team Collaboration, Second Summer 2006

1.7 Extent of Team Collaboration Impact on Individual Performance

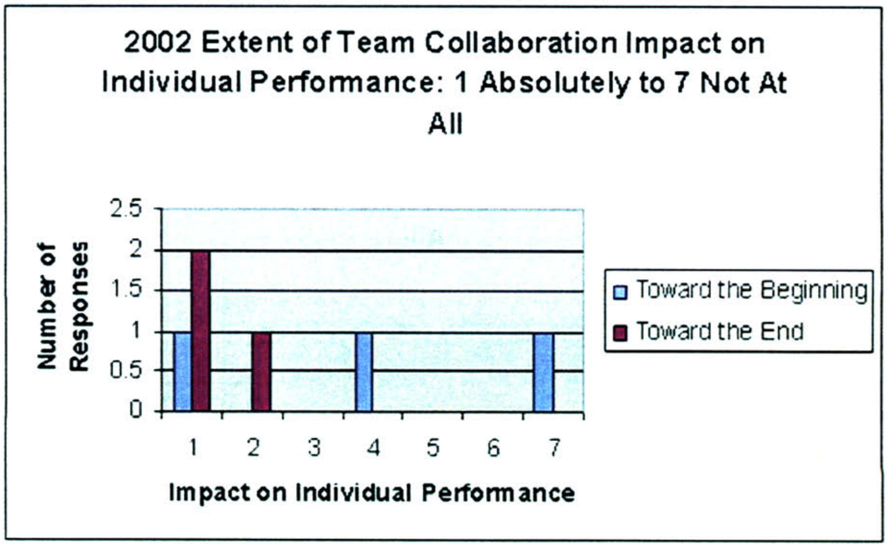
Year 2001 - 42 Students, 6 Responses



	Toward the Beginning	Toward the End
2001 Average	1.83	1.50
2001 Unbiased Standard of Deviation	0.75	0.55
2001-2006 Average	2.38	1.66
2001-2006 Unbiased Standard of Deviation	1.60	1.00

Appendix B Figure 31: Extent of Team Collaboration Impact on Individual Performance, Second Summer 2001

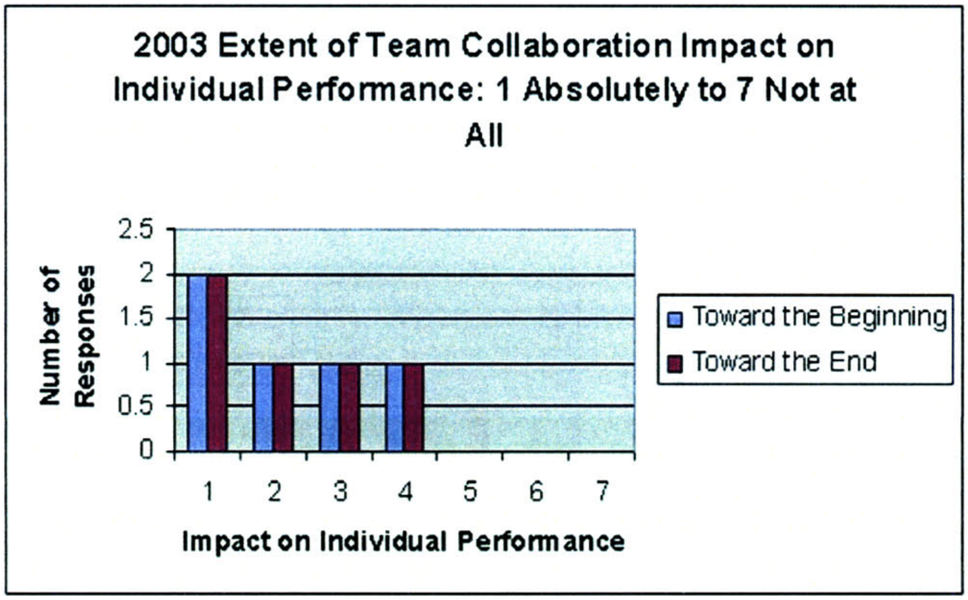
Year 2002 - 27 Students, 3 Responses



	Toward the Beginning	Toward the End
2002 Average	4.00	1.33
2002 Unbiased Standard of Deviation	3.00	0.58
2001-2006 Average	2.38	1.66
2001-2006 Unbiased Standard of Deviation	1.60	1.00

Appendix B Figure 32: Extent of Team Collaboration Impact on Individual Performance, Second Summer 2002

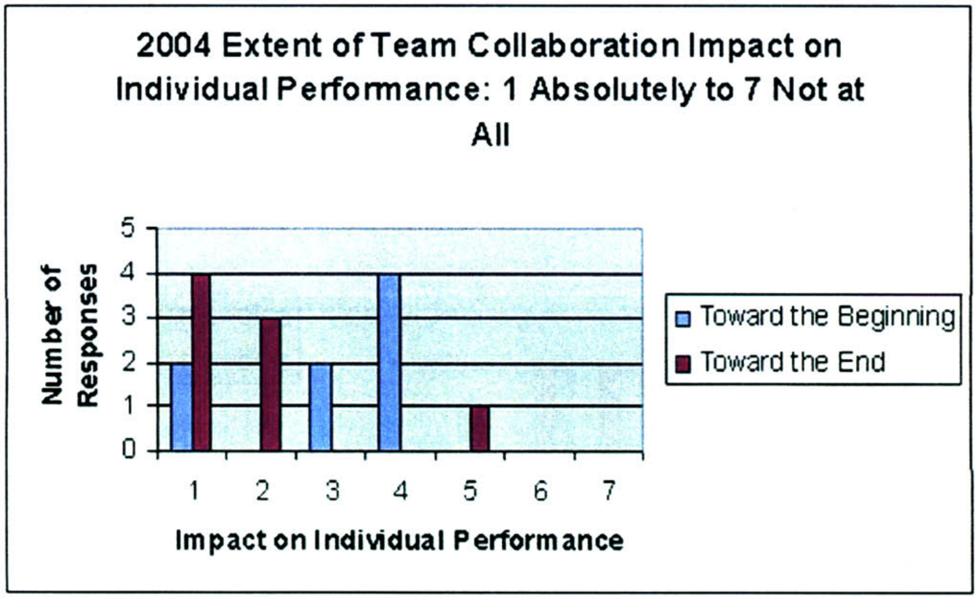
Year 2003 - 28 Students, 5 Responses



	Toward the Beginning	Toward the End
2003 Average	2.00	2.00
2003 Unbiased Standard of Deviation	1.26	1.26
2001-2006 Average	2.38	1.66
2001-2006 Unbiased Standard of Deviation	1.60	1.00

Appendix B Figure 33: Extent of Team Collaboration Impact on Individual Performance, Second Summer 2003

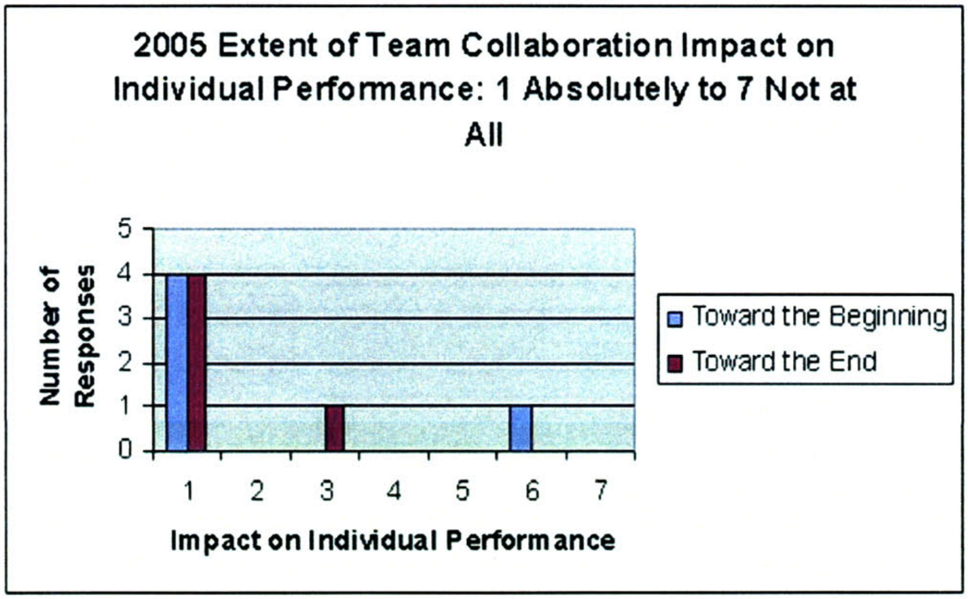
Year 2004 - 29 Students, 8 Responses



	Toward the Beginning	Toward the End
2004 Average	3.00	1.88
2004 Unbiased Standard of Deviation	1.31	1.36
2001-2006 Average	2.38	1.66
2001-2006 Unbiased Standard of Deviation	1.60	1.00

Appendix B Figure 34: Extent of Team Collaboration Impact on Individual Performance, Second Summer 2004

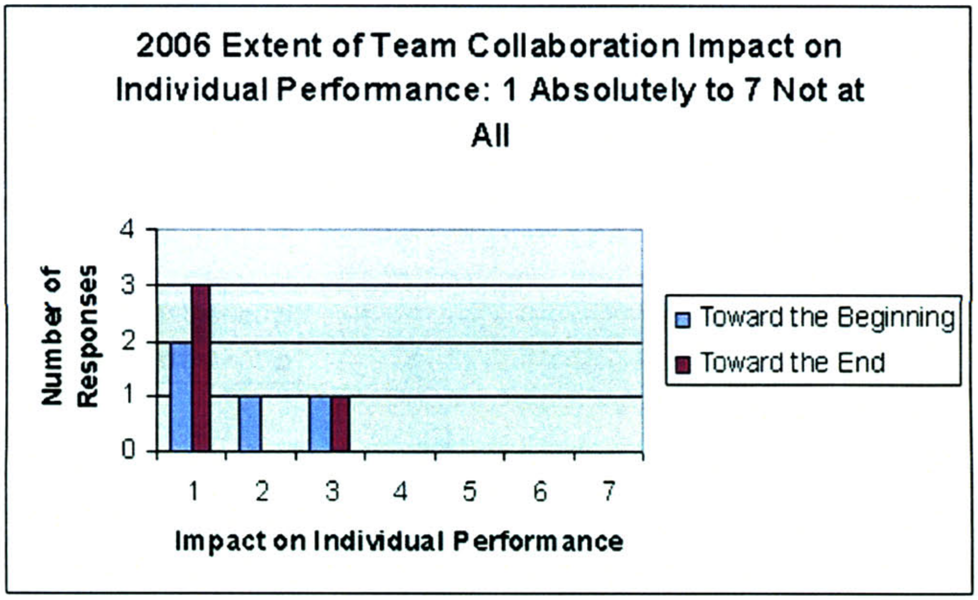
Year 2005 - 19 Students, 5 Responses



	Toward the Beginning	Toward the End
2005 Average	2.00	1.40
2005 Unbiased Standard of Deviation	2.24	0.89
2001-2006 Average	2.38	1.66
2001-2006 Unbiased Standard of Deviation	1.60	1.00

Appendix B Figure 35: Extent of Team Collaboration Impact on Individual Performance, Second Summer 2005

Year 2006 - 10 Students, 4 Responses

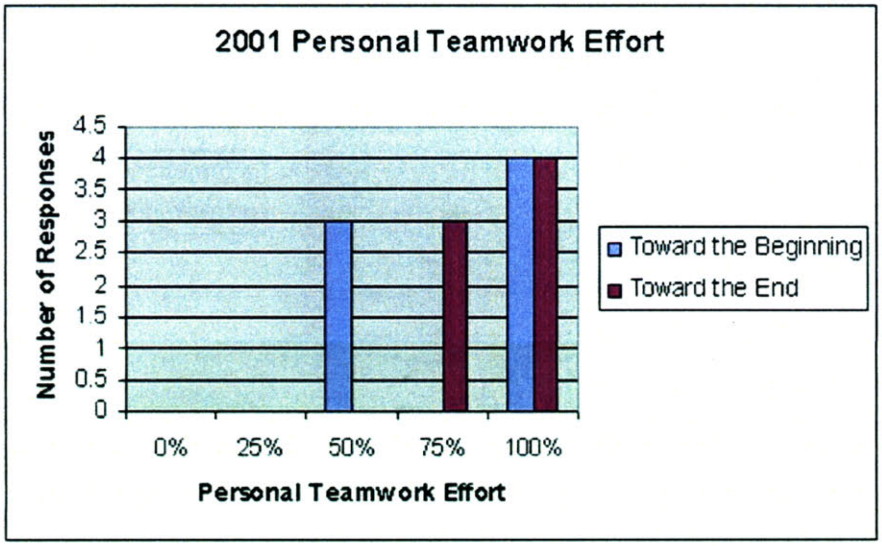


	Toward the Beginning	Toward the End
2006 Average	1.75	1.50
2006 Unbiased Standard of Deviation	0.96	1.00
2001-2006 Average	2.38	1.66
2001-2006 Unbiased Standard of Deviation	1.60	1.00

Appendix B Figure 36: Extent of Team Collaboration Impact on Individual Performance, Second Summer 2006

1.8 Personal Teamwork Effort

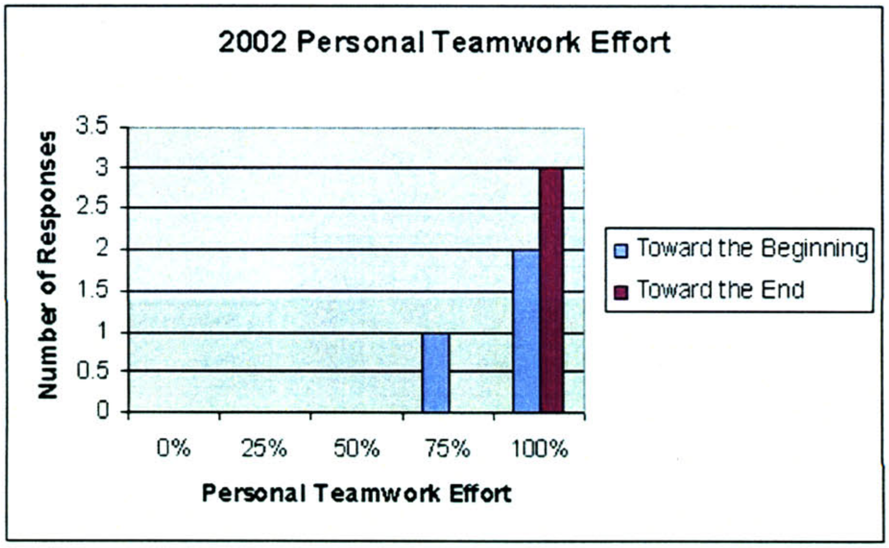
Year 2001 - 42 Students, 7 Responses



	Toward the Beginning	Toward the End
2001 Average	78.57%	89.29%
2001 Unbiased Standard of Deviation	26.73%	13.36%
2001-2006 Average	82.58%	87.88%
2001-2006 Unbiased Standard of Deviation	22.08%	18.88%

Appendix B Figure 37: Personal Teamwork Effort, Second Summer 2001

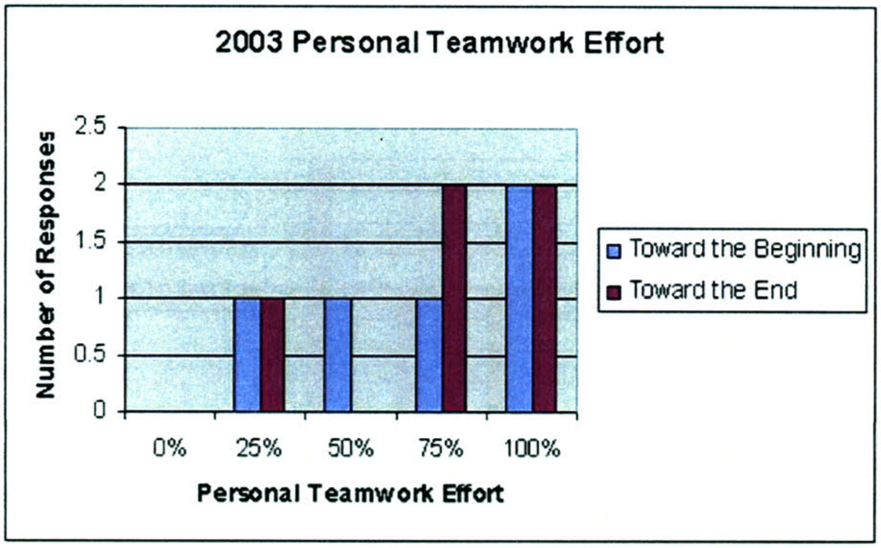
Year 2002 - 27 Students, 3 Responses



	Toward the Beginning	Toward the End
2002 Average	91.67%	100.00%
2002 Unbiased Standard of Deviation	14.43%	0.00%
2001-2006 Average	82.58%	87.88%
2001-2006 Unbiased Standard of Deviation	22.08%	18.88%

Appendix B Figure 38: Personal Teamwork Effort, Second Summer 2002

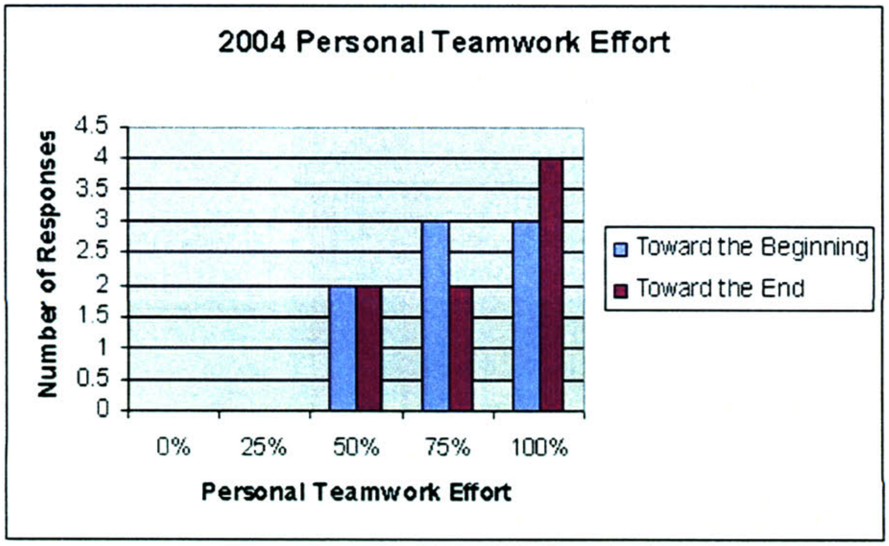
Year 2003 - 28 Students, 5 Responses



	Toward the Beginning	Toward the End
2003 Average	70.83%	79.17%
2003 Unbiased Standard of Deviation	29.23%	29.23%
2001-2006 Average	82.58%	87.88%
2001-2006 Unbiased Standard of Deviation	22.08%	18.88%

Appendix B Figure 39: Personal Teamwork Effort, Second Summer 2003

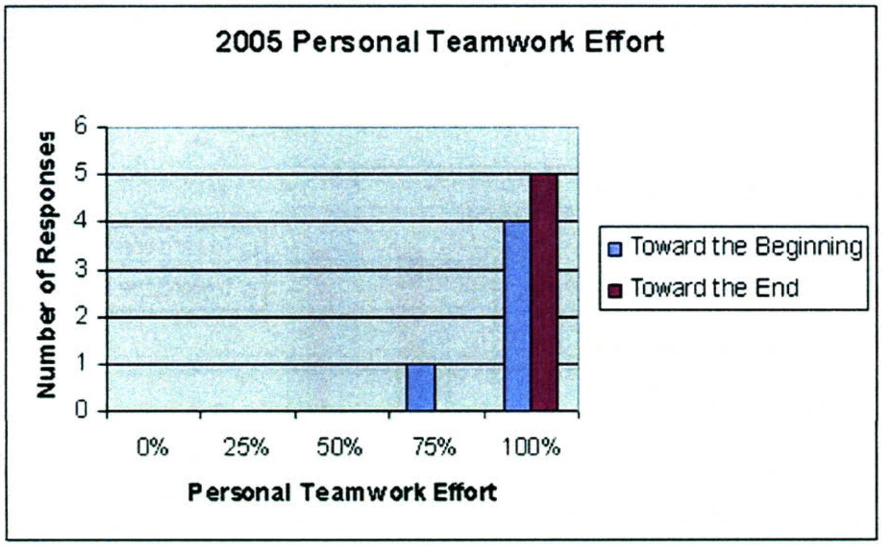
Year 2004 - 29 Students, 8 Responses



	Toward the Beginning	Toward the End
2004 Average	78.13%	81.25%
2004 Unbiased Standard of Deviation	20.86%	22.16%
2001-2006 Average	82.58%	87.88%
2001-2006 Unbiased Standard of Deviation	22.08%	18.88%

Appendix B Figure 40: Personal Teamwork Effort, Second Summer 2004

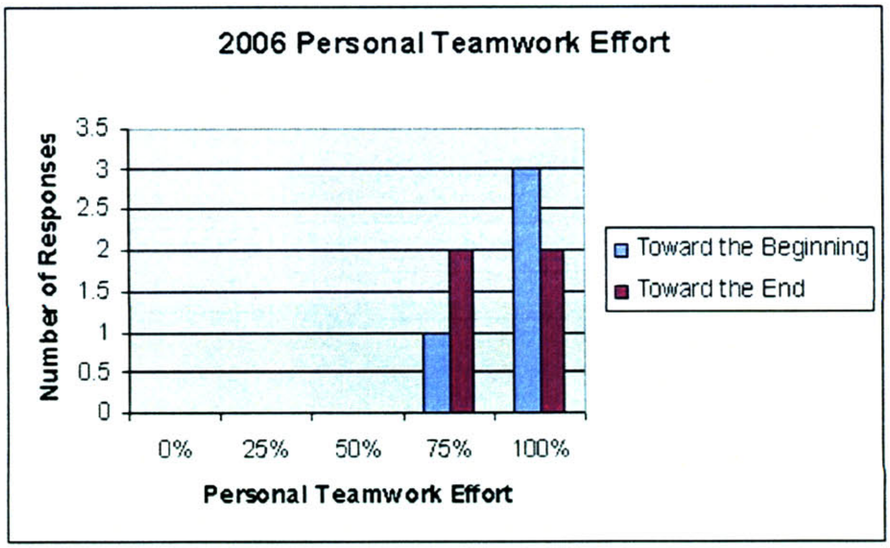
Year 2005 - 19 Students, 5 Responses



	Toward the Beginning	Toward the End
2005 Average	95.00%	100%
2005 Unbiased Standard of Deviation	11.18%	0%
2001-2006 Average	82.58%	87.88%
2001-2006 Unbiased Standard of Deviation	22.08%	18.88%

Appendix B Figure 41: Personal Teamwork Effort, Second Summer 2005

Year 2006 - 10 Students, 4 Responses

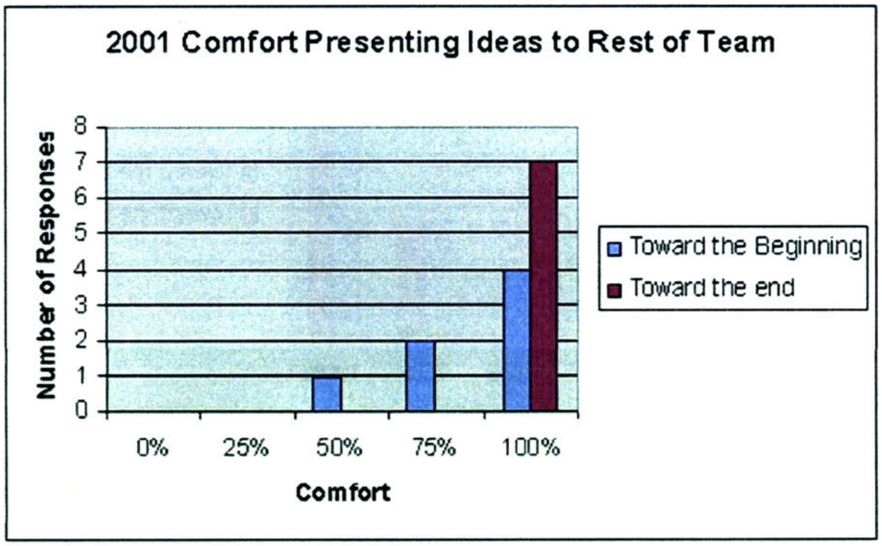


	Toward the Beginning	Toward the End
2006 Average	93.75%	87.50%
2006 Unbiased Standard of Deviation	12.50%	14.43%
2001-2006 Average	82.58%	87.88%
2001-2006 Unbiased Standard of Deviation	22.08%	18.88%

Appendix B Figure 42: Personal Teamwork Effort, Second Summer 2006

1.9 Comfort Presenting Ideas to Rest of Team

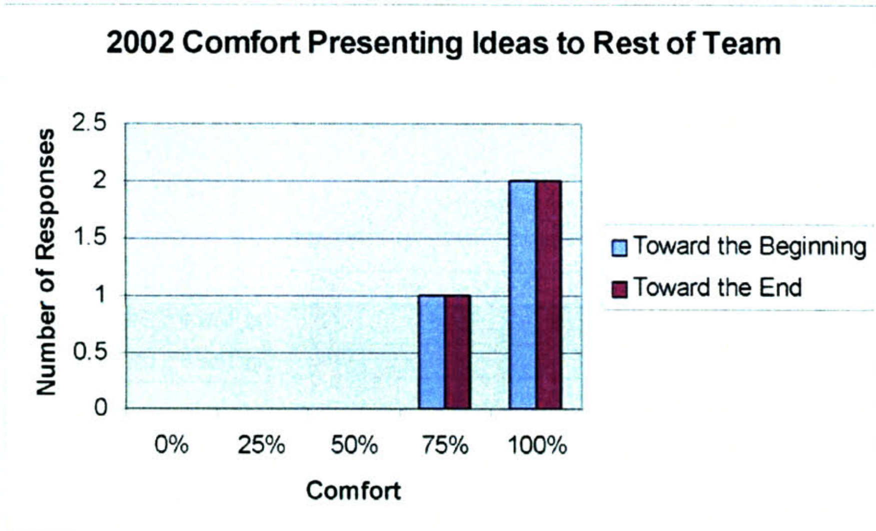
Year 2001 - 42 Students, 7 Responses



	Toward the Beginning	Toward the End
2001 Average	85.71%	100.00%
2001 Unbiased Standard of Deviation	19.67%	0.00%
2001-2006 Average	87.88%	93.94%
2001-2006 Unbiased Standard of Deviation	20.84%	14.02%

Appendix B Figure 43: Comfort Presenting Ideas to Rest of Team, Second Summer 2001

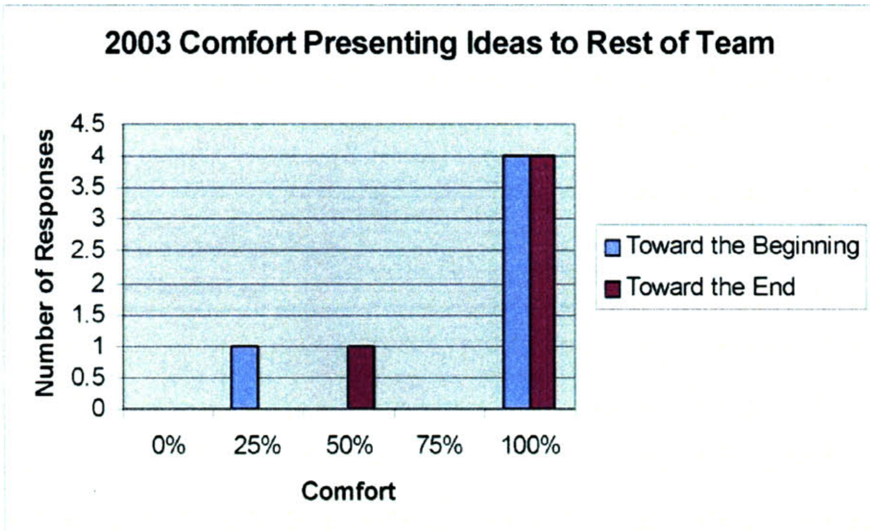
Year 2002 - 27 Students, 3 Responses



	Toward the Beginning	Toward the End
2002 Average	91.67%	91.67%
2002 Unbiased Standard of Deviation	14.43%	14.43%
2001-2006 Average	87.88%	93.94%
2001-2006 Unbiased Standard of Deviation	20.84%	14.02%

Appendix B Figure 44: Comfort Presenting Ideas to Rest of Team, Second Summer 2002

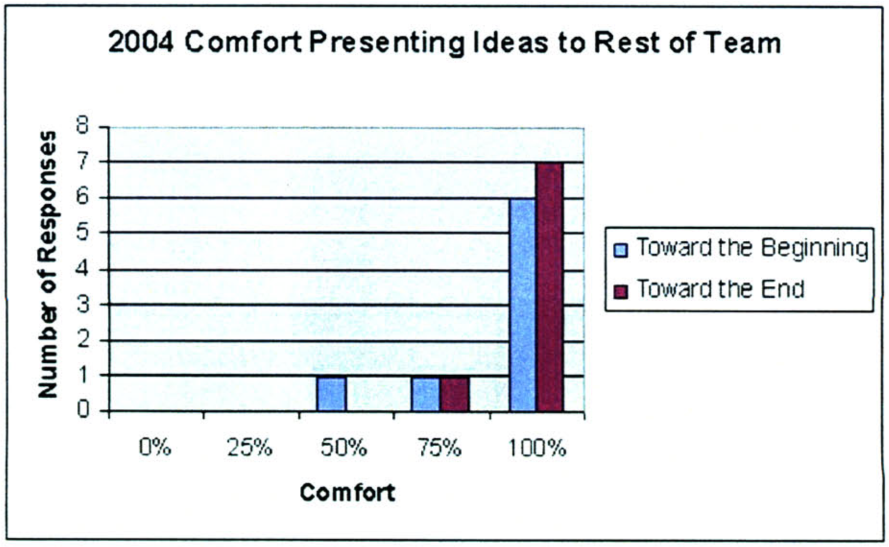
Year 2003 - 28 Students, 5 Responses



	Toward the Beginning	Toward the End
2003 Average	87.50%	91.67%
2003 Unbiased Standard of Deviation	30.62%	20.41%
2001-2006 Average	87.88%	93.94%
2001-2006 Unbiased Standard of Deviation	20.84%	14.02%

Appendix B Figure 45: Comfort Presenting Ideas to Rest of Team, Second Summer 2003

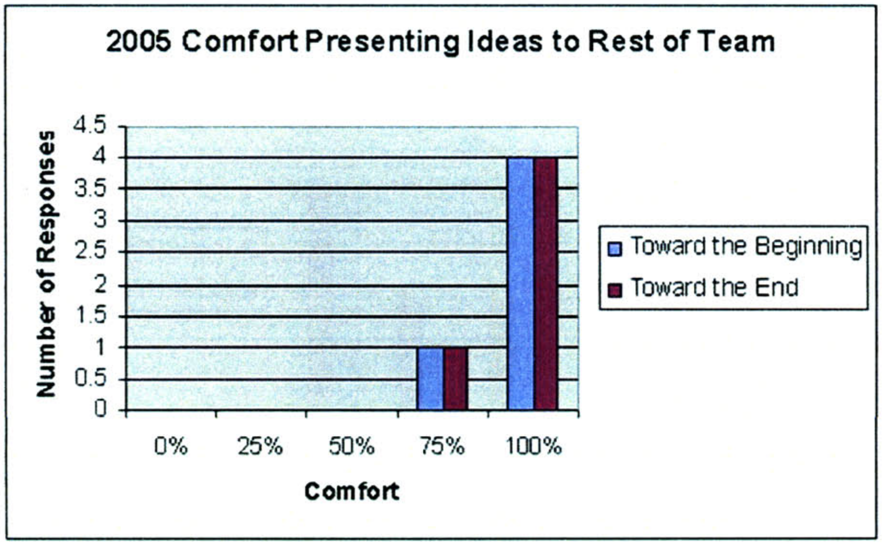
Year 2004 - 29 Students, 8 Responses



	Toward the Beginning	Toward the End
2004 Average	90.63%	96.88%
2004 Unbiased Standard of Deviation	18.60%	8.84%
2001-2006 Average	87.88%	93.94%
2001-2006 Unbiased Standard of Deviation	20.84%	14.02%

Appendix B Figure 46: Comfort Presenting Ideas to Rest of Team, Second Summer 2004

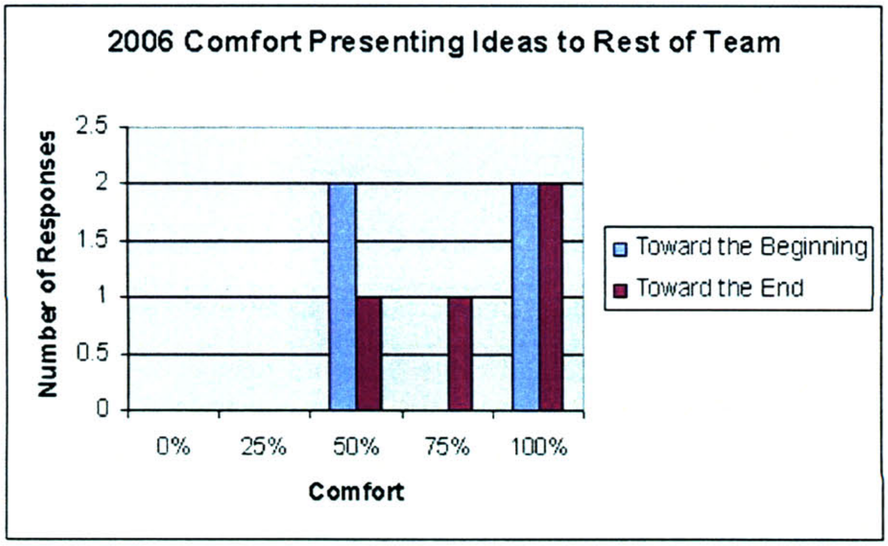
Year 2005 - 19 Students, 5 Responses



	Toward the Beginning	Toward the End
2005 Average	95.00%	95.00%
2005 Unbiased Standard of Deviation	11.18%	11.18%
2001-2006 Average	87.88%	93.94%
2001-2006 Unbiased Standard of Deviation	20.84%	14.02%

Appendix B Figure 47: Comfort Presenting Ideas to Rest of Team, Second Summer 2005

Year 2006 - 10 Students, 4 Responses

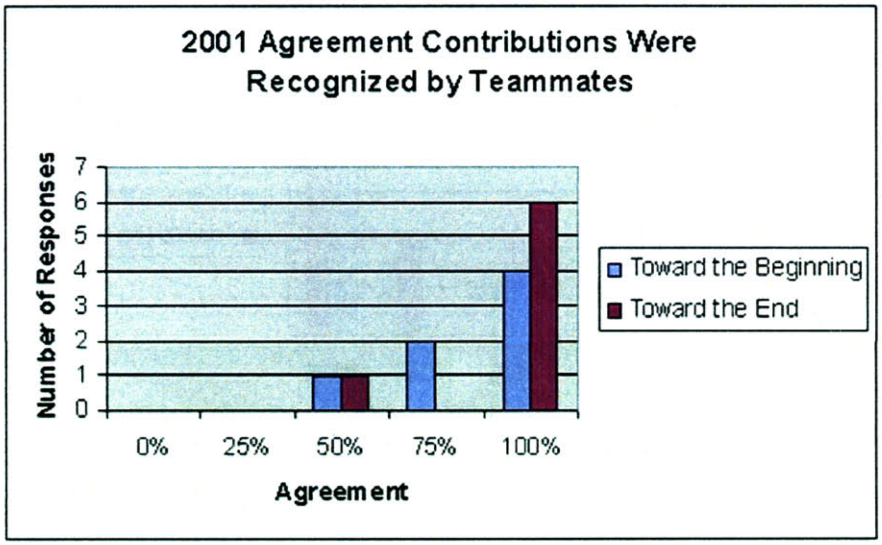


	Toward the Beginning	Toward the End
2006 Average	75.00%	81.25%
2006 Unbiased Standard of Deviation	28.87%	23.94%
2001-2006 Average	87.88%	93.94%
2001-2006 Unbiased Standard of Deviation	20.84%	14.02%

Appendix B Figure 48: Comfort Presenting Ideas to Rest of Team, Second Summer 2006

1.10 Agreement Contributions Were Recognized by Teammates

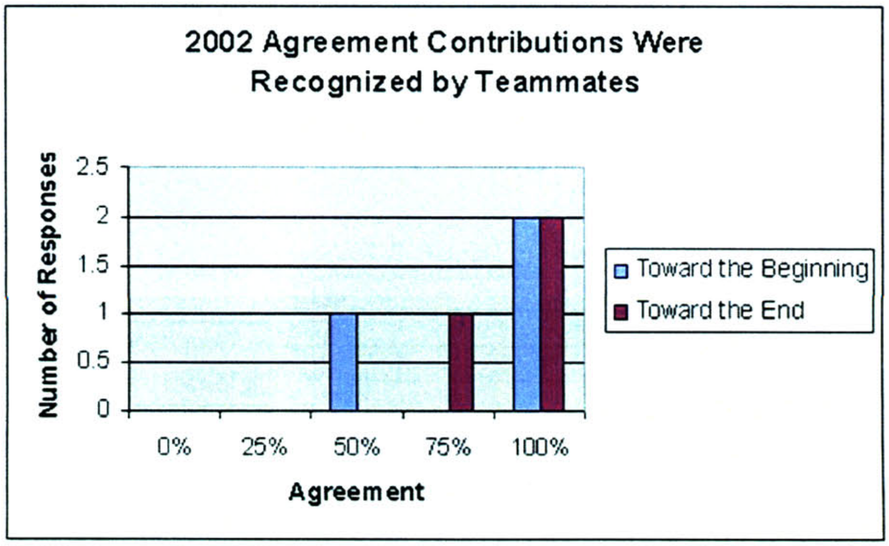
Year 2001 - 42 Students, 7 Responses



	Toward the Beginning	Toward the End
2001 Average	85.71%	92.86%
2001 Unbiased Standard of Deviation	19.67%	18.90%
2001-2006 Average	82.03%	86.72%
2001-2006 Unbiased Standard of Deviation	22.21%	21.05%

Appendix B Figure 49: Agreement Contributions Were Recognized by Teammates, Second Summer 2001

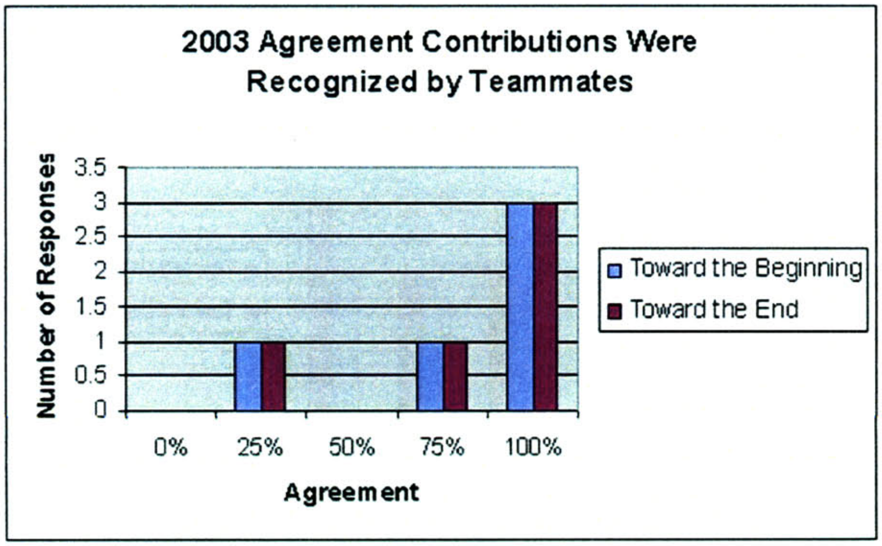
Year 2002 - 27 Students, 3 Responses



	Toward the Beginning	Toward the End
2002 Average	83.33%	91.67%
2002 Unbiased Standard of Deviation	28.87%	14.43%
2001-2006 Average	82.03%	86.72%
2001-2006 Unbiased Standard of Deviation	22.21%	21.05%

Appendix B Figure 50: Agreement Contributions Were Recognized by Teammates, Second Summer 2002

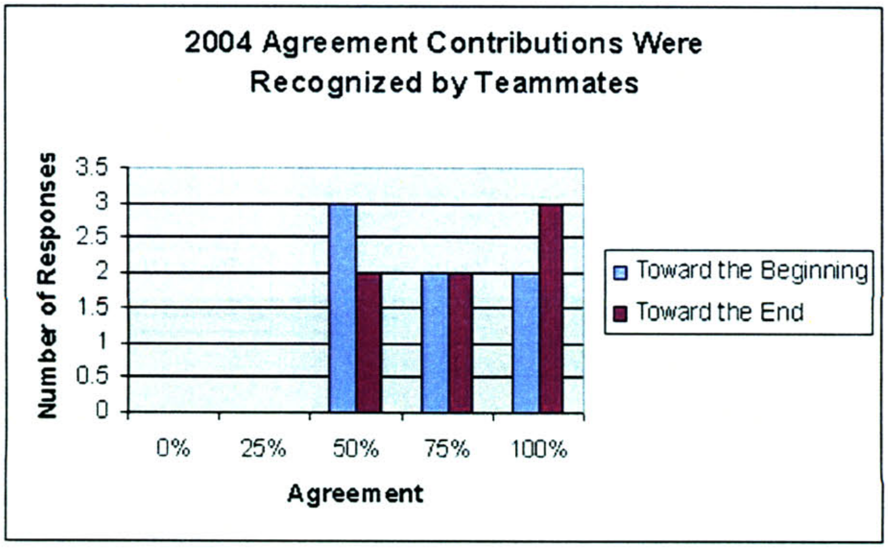
Year 2003 - 28 Students, 5 Responses



	Toward the Beginning	Toward the End
2003 Average	79.17%	79.17%
2003 Unbiased Standard of Deviation	29.23%	29.23%
2001-2006 Average	82.03%	86.72%
2001-2006 Unbiased Standard of Deviation	22.21%	21.05%

Appendix B Figure 51: Agreement Contributions Were Recognized by Teammates, Second Summer 2003

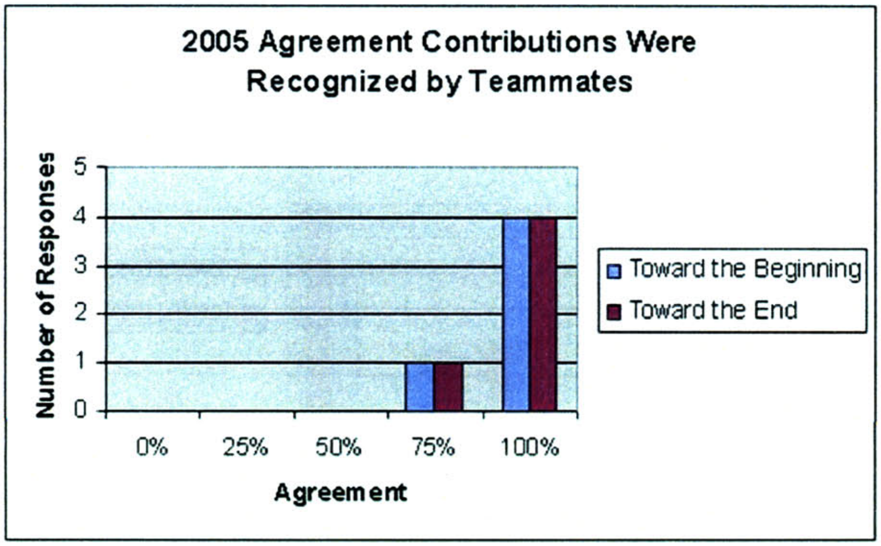
Year 2004 - 29 Students, 7 Responses



	Toward the Beginning	Toward the End
2004 Average	71.43%	78.57%
2004 Unbiased Standard of Deviation	22.49%	22.49%
2001-2006 Average	82.03%	86.72%
2001-2006 Unbiased Standard of Deviation	22.21%	21.05%

Appendix B Figure 52: Agreement Contributions Were Recognized by Teammates, Second Summer 2004

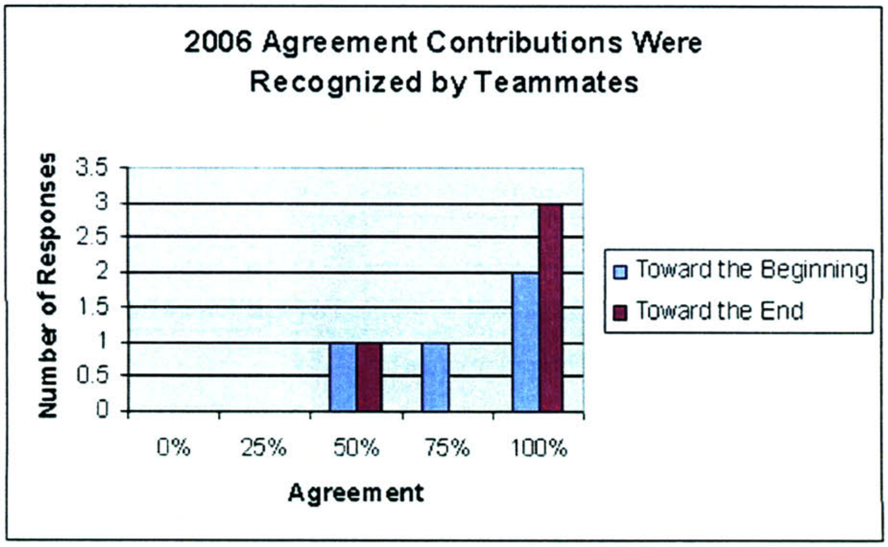
Year 2005 - 19 Students, 5 Responses



	Toward the Beginning	Toward the End
2005 Average	95.00%	95.00%
2005 Unbiased Standard of Deviation	11.18%	11.18%
2001-2006 Average	82.03%	86.72%
2001-2006 Unbiased Standard of Deviation	22.21%	21.05%

Appendix B Figure 53: Agreement Contributions Were Recognized by Teammates, Second Summer 2005

Year 2006 - 10 Students, 4 Responses

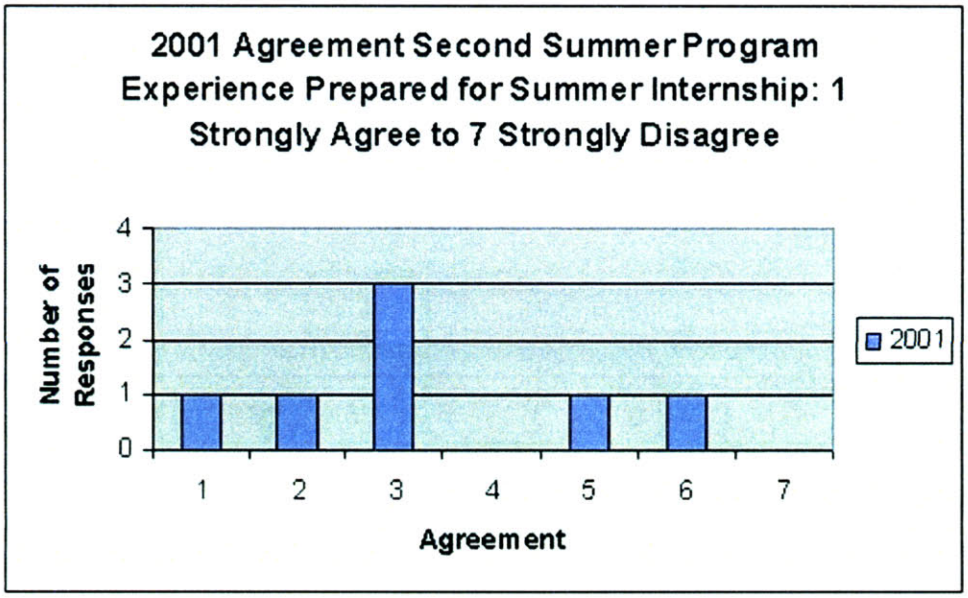


	Toward the Beginning	Toward the End
2006 Average	81.25%	87.50%
2006 Unbiased Standard of Deviation	23.94%	25.00%
2001-2006 Average	82.03%	86.72%
2001-2006 Unbiased Standard of Deviation	22.21%	21.05%

Appendix B Figure 54: Agreement Contributions Were Recognized by Teammates, Second Summer 2006

1.11 Agreement SSP Experience Prepared for Summer Internship

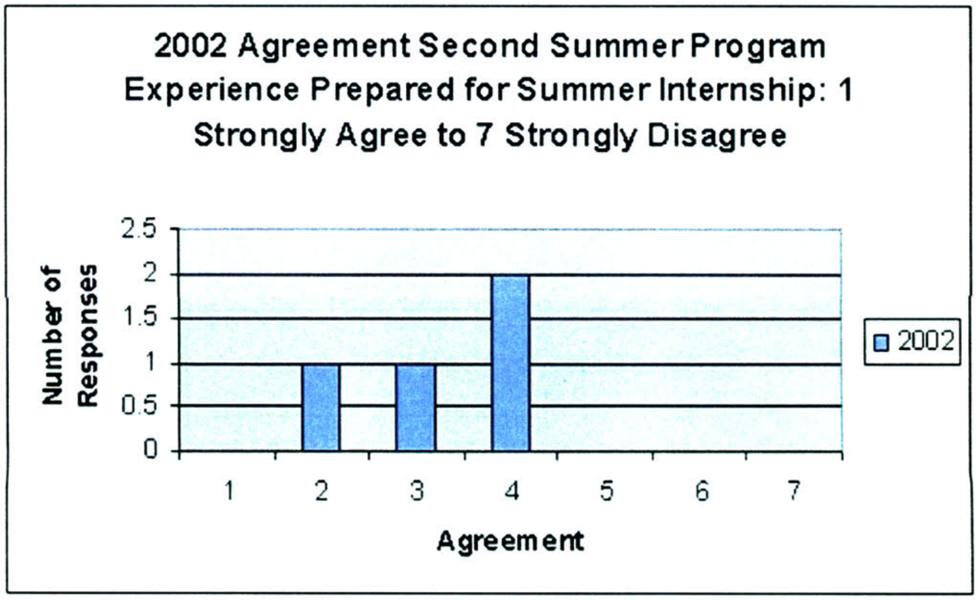
Year 2001 - 42 Students, 7 Responses



	Agree - Disagree
2001 Average	3.29
2001 Unbiased Standard of Deviation	1.70
2001-2006 Average	3.03
2001-2006 Unbiased Standard of Deviation	1.47

Appendix B Figure 55: Agreement Second Summer Program Experience Prepared for Summer Internship, Second Summer 2001

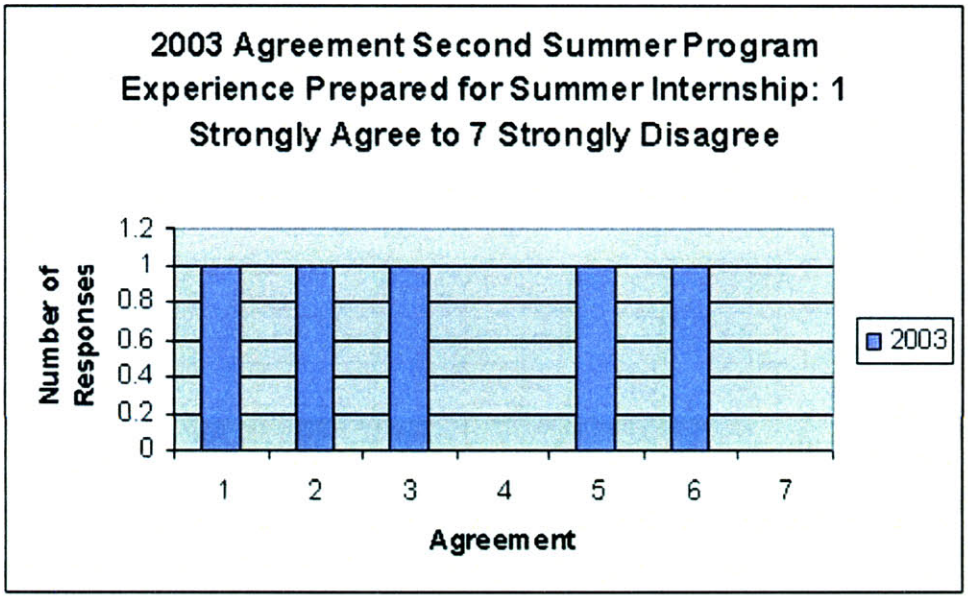
Year 2002 - 27 Students, 4 Responses



	Agree - Disagree
2002 Average	3.25
2002 Unbiased Standard of Deviation	0.96
2001-2006 Average	3.03
2001-2006 Unbiased Standard of Deviation	1.47

Appendix B Figure 56: Agreement Second Summer Program Experience Prepared for Summer Internship, Second Summer 2002

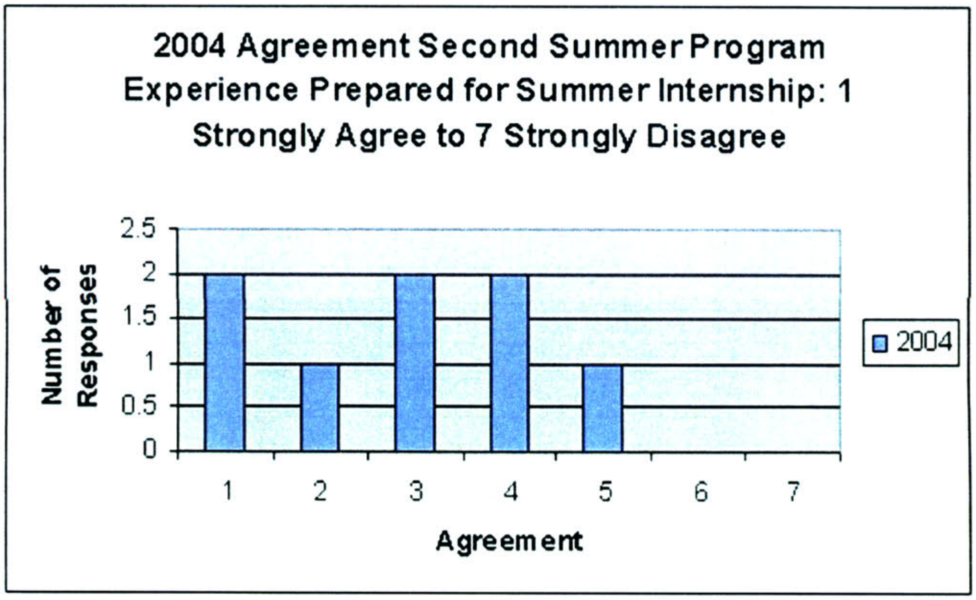
Year 2003 - 28 Students, 5 Responses



	Agree - Disagree
2003 Average	3.17
2003 Unbiased Standard of Deviation	1.94
2001-2006 Average	3.03
2001-2006 Unbiased Standard of Deviation	1.47

Appendix B Figure 57: Agreement Second Summer Program Experience Prepared for Summer Internship, Second Summer 2003

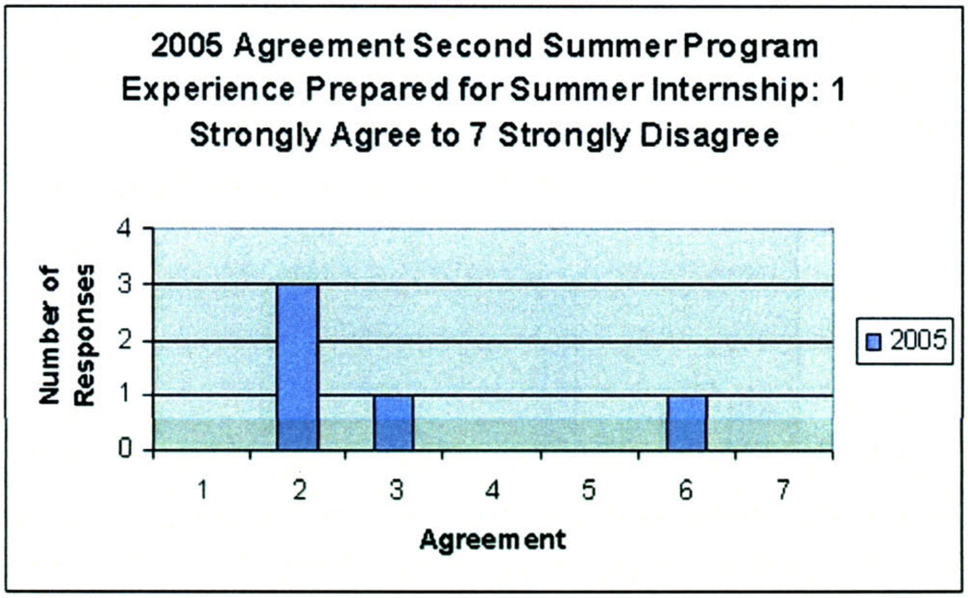
Year 2004 - 29 Students, 8 Responses



	Agree - Disagree
2004 Average	2.88
2004 Unbiased Standard of Deviation	1.46
2001-2006 Average	3.03
2001-2006 Unbiased Standard of Deviation	1.47

Appendix B Figure 58: Agreement Second Summer Program Experience Prepared for Summer Internship, Second Summer 2004

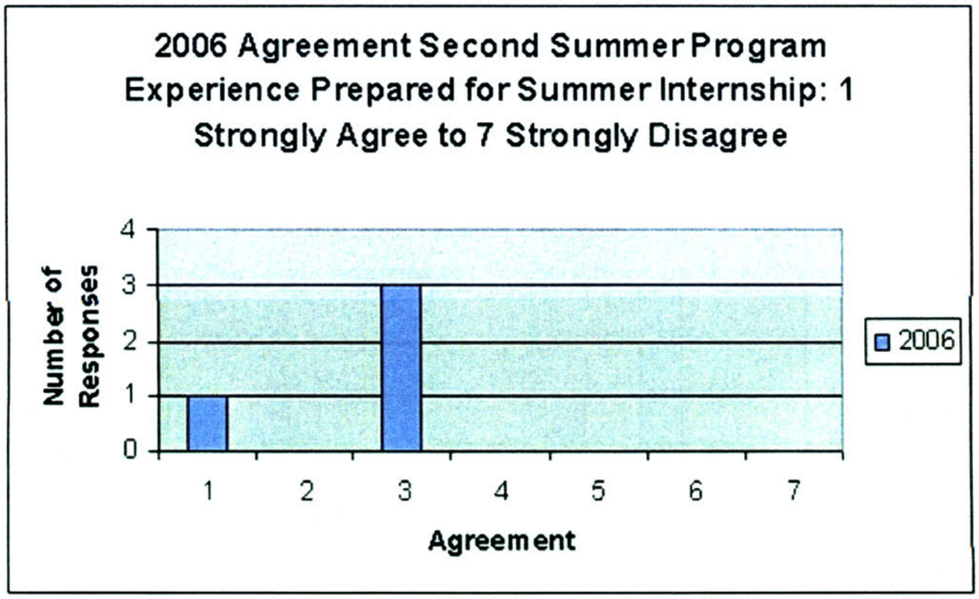
Year 2005 - 19 Students, 5 Responses



	Agree - Disagree
2005 Average	3.00
2005 Unbiased Standard of Deviation	1.73
2001-2006 Average	3.03
2001-2006 Unbiased Standard of Deviation	1.47

Appendix B Figure 59: Agreement Second Summer Program Experience Prepared for Summer Internship, Second Summer 2005

Year 2006 - 10 Students, 4 Responses

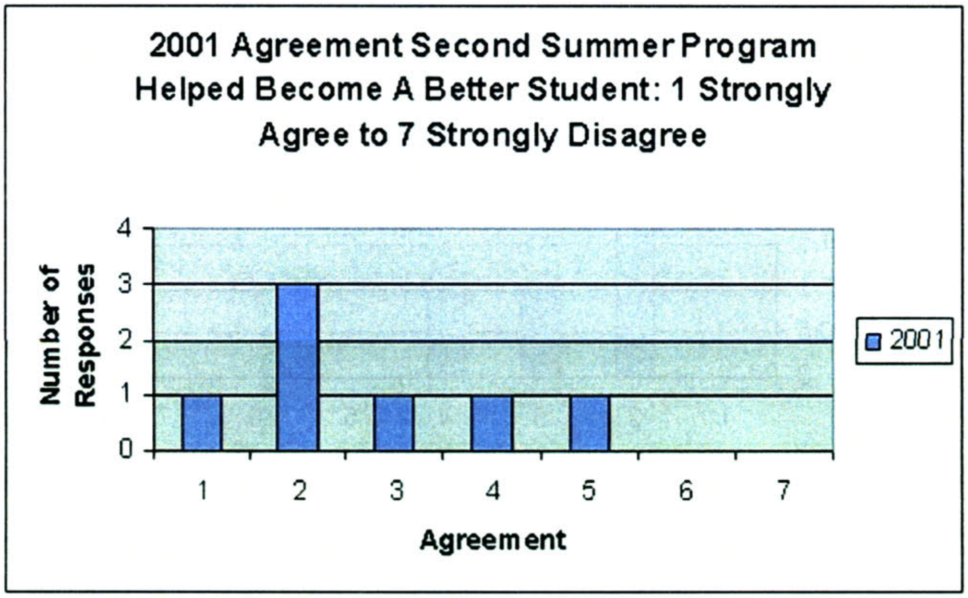


	Agree - Disagree
2006 Average	2.50
2006 Unbiased Standard of Deviation	1.00
2001-2006 Average	3.03
2001-2006 Unbiased Standard of Deviation	1.47

Appendix B Figure 60: Agreement Second Summer Program Experience Prepared for Summer Internship, Second Summer 2006

1.12 Agreement SSP Helped Become A Better Student

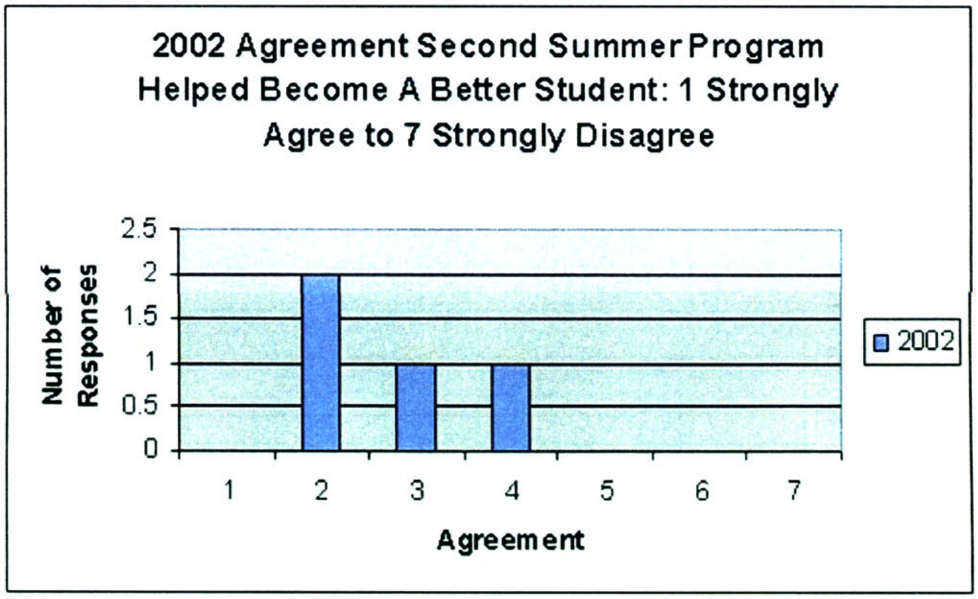
Year 2001 - 42 Students, 7 Responses



	Agree - Disagree
2001 Average	2.71
2001 Unbiased Standard of Deviation	1.38
2001-2006 Average	2.97
2001-2006 Unbiased Standard of Deviation	1.66

Appendix B Figure 61: Agreement Second Summer Program Helped Become A Better Student, Second Summer 2001

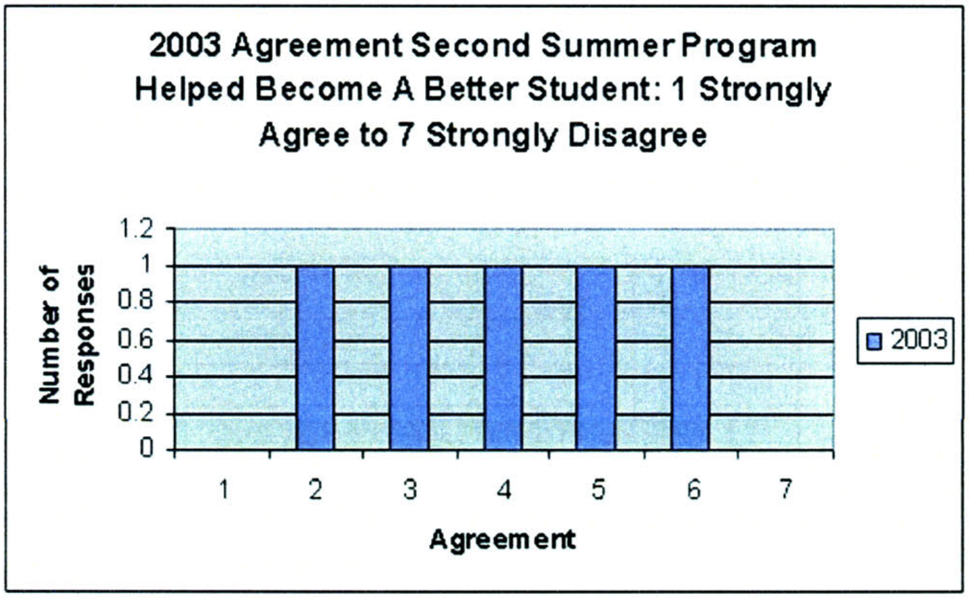
Year 2002 - 27 Students, 4 Responses



	Agree - Disagree
2002 Average	2.75
2002 Unbiased Standard of Deviation	0.96
2001-2006 Average	2.97
2001-2006 Unbiased Standard of Deviation	1.66

Appendix B Figure 62: Agreement Second Summer Program Helped Become A Better Student, Second Summer 2002

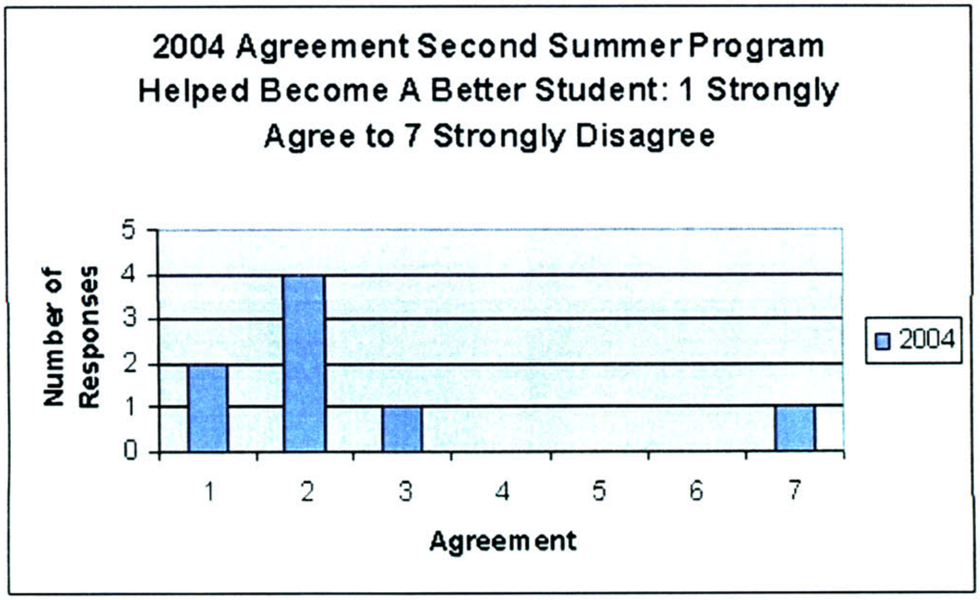
Year 2003 - 28 Students, 5 Responses



	Agree - Disagree
2003 Average	3.67
2003 Unbiased Standard of Deviation	1.63
2001-2006 Average	2.97
2001-2006 Unbiased Standard of Deviation	1.66

Appendix B Figure 63: Agreement Second Summer Program Helped Become A Better Student, Second Summer 2003

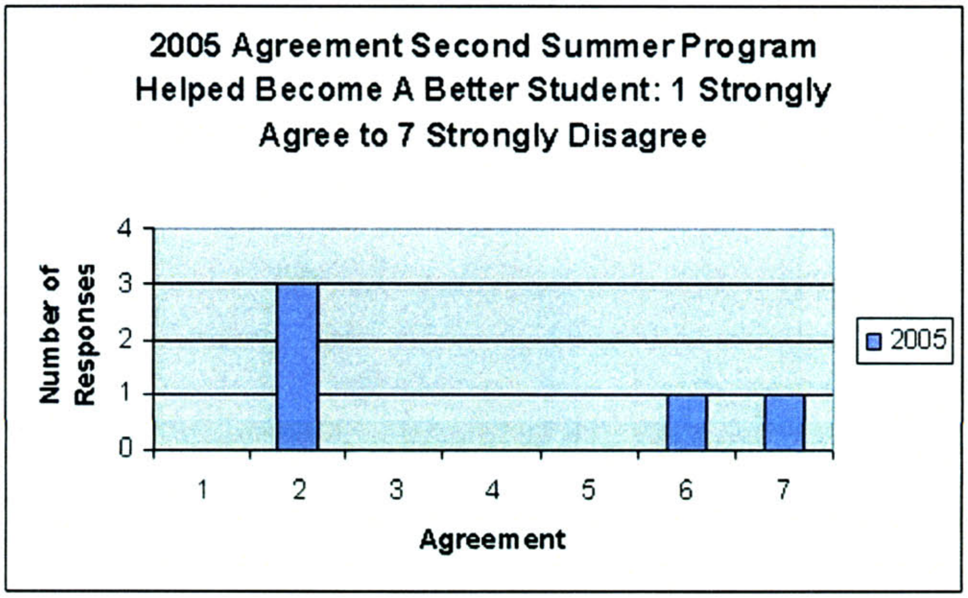
Year 2004 - 29 Students, 8 Responses



	Agree - Disagree
2004 Average	2.50
2004 Unbiased Standard of Deviation	1.93
2001-2006 Average	2.97
2001-2006 Unbiased Standard of Deviation	1.66

Appendix B Figure 64: Agreement Second Summer Program Helped Become A Better Student, Second Summer 2004

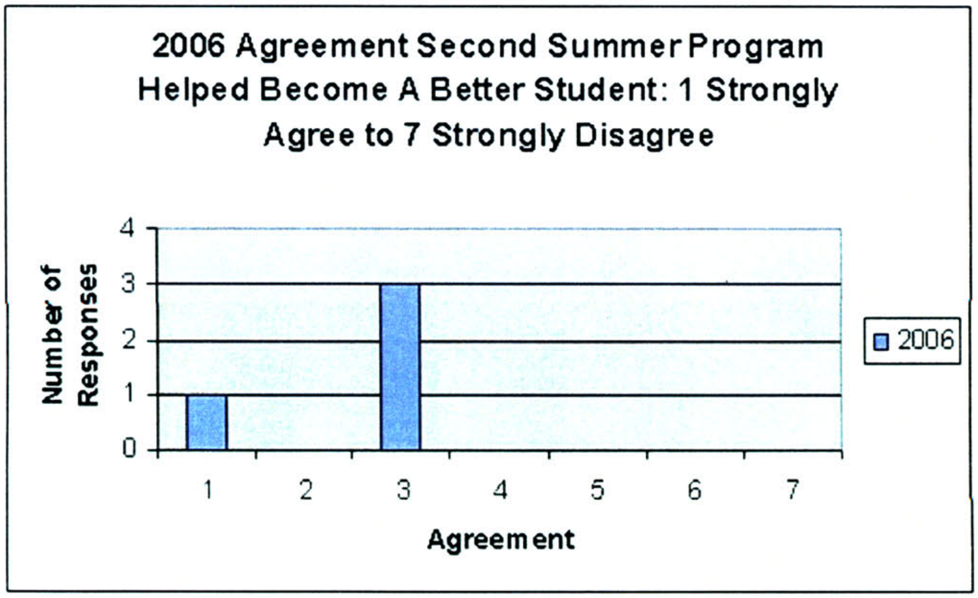
Year 2005 - 19 Students, 5 Responses



	Agree - Disagree
2005 Average	3.80
2005 Unbiased Standard of Deviation	2.49
2001-2006 Average	2.97
2001-2006 Unbiased Standard of Deviation	1.66

Appendix B Figure 65: Agreement Second Summer Program Helped Become A Better Student, Second Summer 2005

Year 2006 - 10 Students, 4 Responses



	Agree - Disagree
2006 Average	2.50
2006 Unbiased Standard of Deviation	1.00
2001-2006 Average	2.97
2001-2006 Unbiased Standard of Deviation	1.66

Appendix B Figure 66: Agreement Second Summer Program Helped Become A Better Student, Second Summer 2006

1.13 Satisfaction with Course

Year 2001 - 42 Students, 7 Responses

	Very Unsatisfied - Very Satisfied
2001 Average	4.71
2001 Unbiased Standard of Deviation	1.70
2001-2006 Average	4.94
2001-2006 Unbiased Standard of Deviation	1.84

Appendix B Figure 67: Satisfaction with Course, Second Summer 2001

Year 2002 - 27 Students, 4 Responses

	Very Unsatisfied - Very Satisfied
2002 Average	3.25
2002 Unbiased Standard of Deviation	2.50
2001-2006 Average	4.94
2001-2006 Unbiased Standard of Deviation	1.84

Appendix B Figure 68: Satisfaction with Course, Second Summer 2002

Year 2003 - 28 Students, 5 Responses

	Very Unsatisfied - Very Satisfied
2003 Average	5.00
2003 Unbiased Standard of Deviation	2.00
2001-2006 Average	4.94
2001-2006 Unbiased Standard of Deviation	1.84

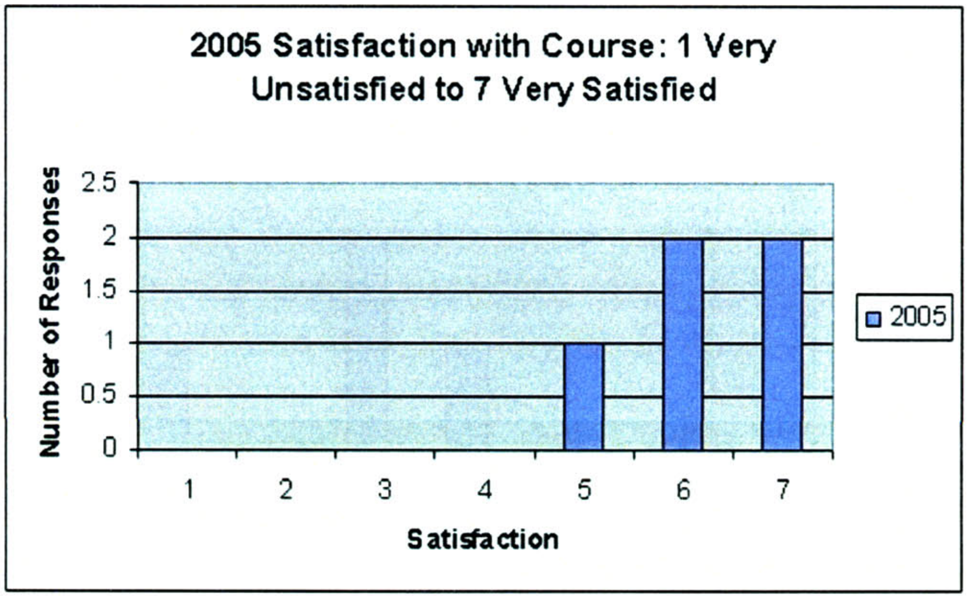
Appendix B Figure 69: Satisfaction with Course, Second Summer 2003

Year 2004 - 29 Students, 8 Responses

	Very Unsatisfied - Very Satisfied
2004 Average	5.00
2004 Unbiased Standard of Deviation	2.00
2001-2006 Average	4.94
2001-2006 Unbiased Standard of Deviation	1.84

Appendix B Figure 70: Satisfaction with Course, Second Summer 2004

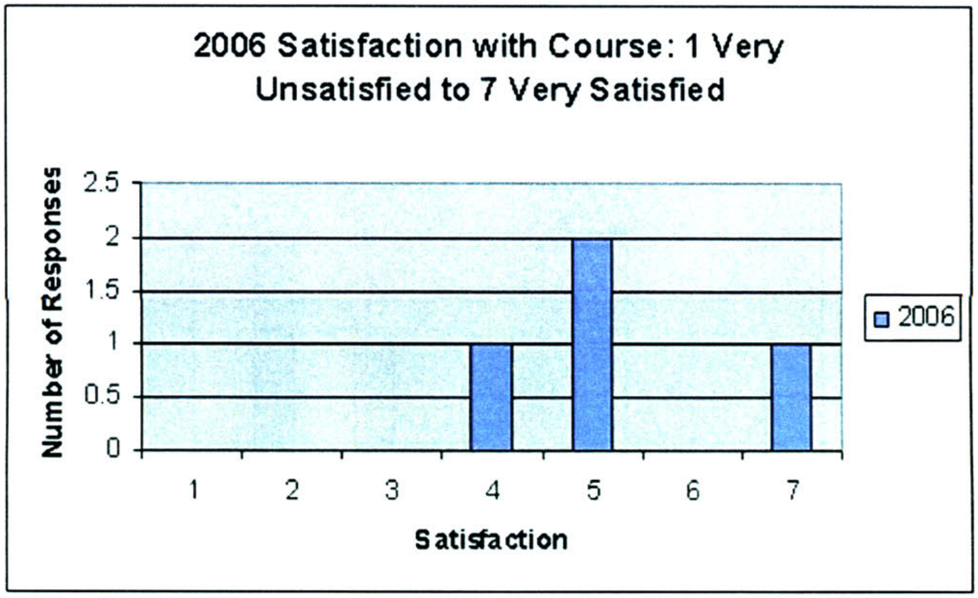
Year 2005 - 19 Students, 5 Responses



	Very Unsatisfied - Very Satisfied
2005 Average	6.20
2005 Unbiased Standard of Deviation	0.84
2001-2006 Average	4.94
2001-2006 Unbiased Standard of Deviation	1.84

Appendix B Figure 71: Satisfaction with Course, Second Summer 2005

Year 2006 - 10 Students, 4 Responses

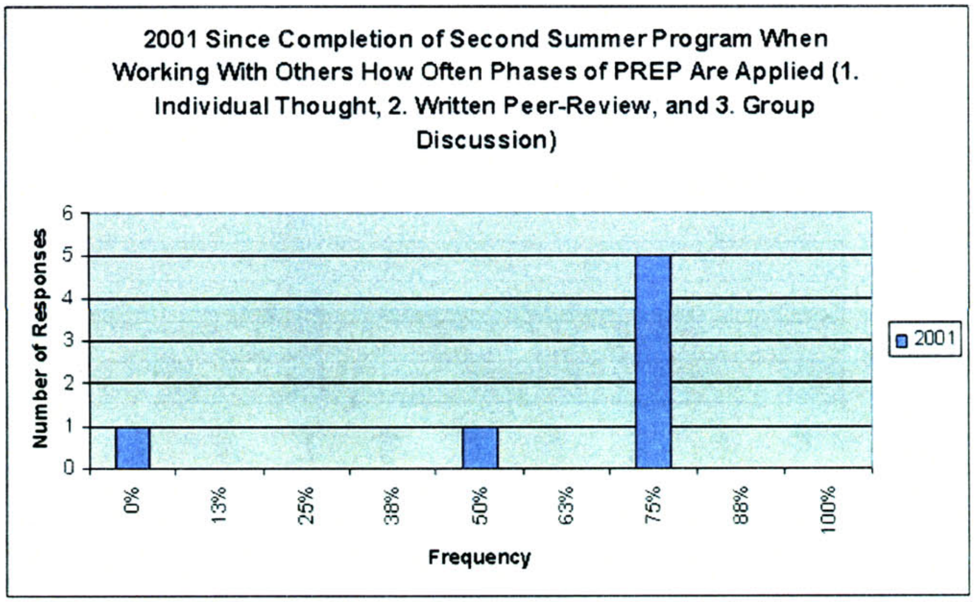


	Very Unsatisfied - Very Satisfied
2006 Average	5.25
2006 Unbiased Standard of Deviation	1.26
2001-2006 Average	4.94
2001-2006 Unbiased Standard of Deviation	1.84

Appendix B Figure 72: Satisfaction with Course, Second Summer 2006

1.14 Since Program How Often Apply PREP When Working With Others

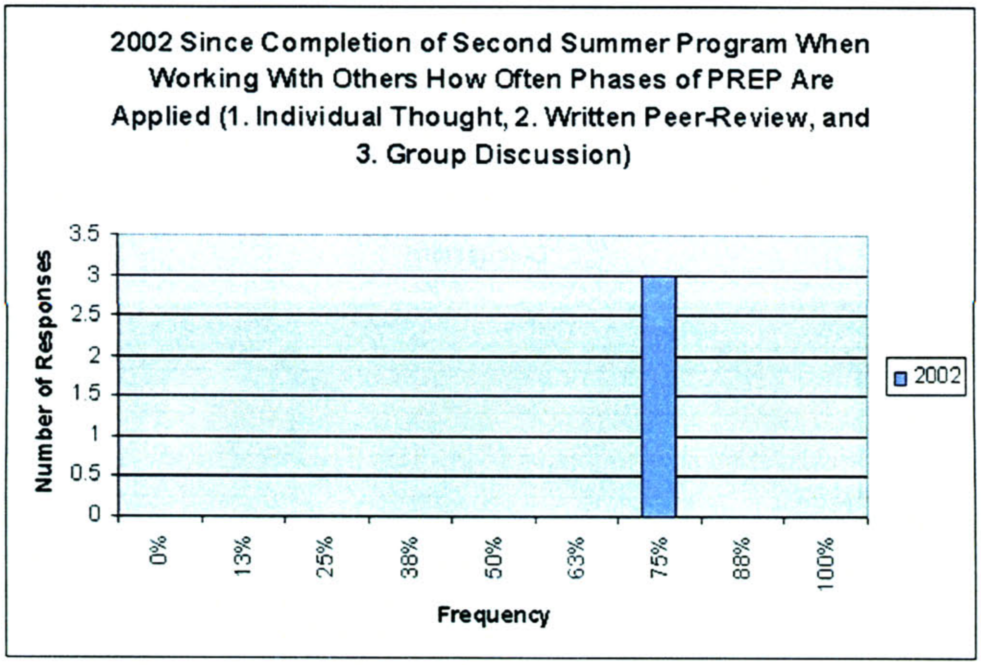
Year 2001 - 42 Students, 7 Responses



	Frequency
2001 Average	60.71%
2001 Unbiased Standard of Deviation	28.35%
2001-2006 Average	54.92%
2001-2006 Unbiased Standard of Deviation	26.51%

Appendix B Figure 73: Since Program How Often Apply PREP When Working With Others, Second Summer 2001

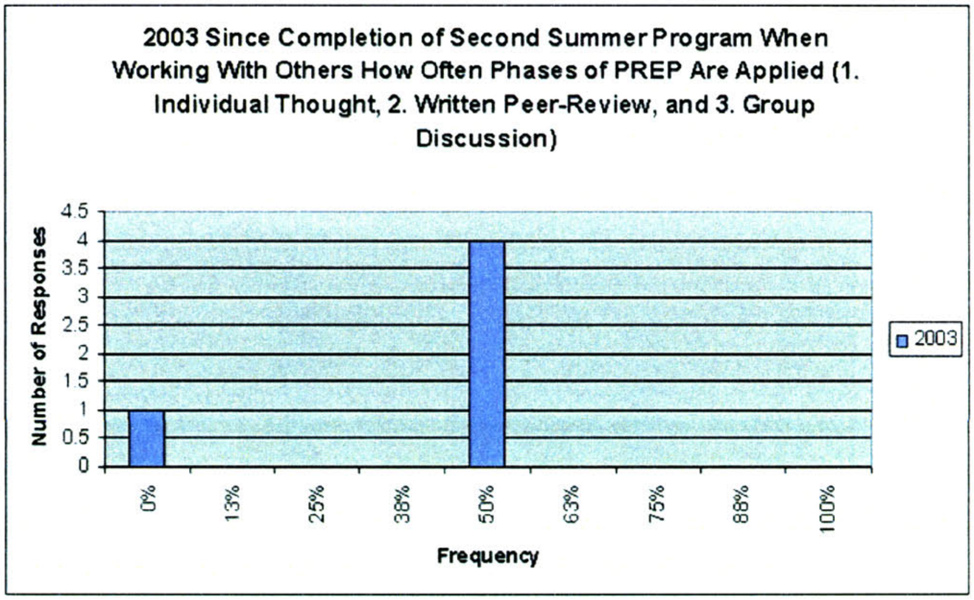
Year 2002 - 27 Students, 3 Responses



	Frequency
2002 Average	75.00%
2002 Unbiased Standard of Deviation	0.00%
2001-2006 Average	54.92%
2001-2006 Unbiased Standard of Deviation	26.51%

Appendix B Figure 74: Since Program How Often Apply PREP When Working With Others, Second Summer 2002

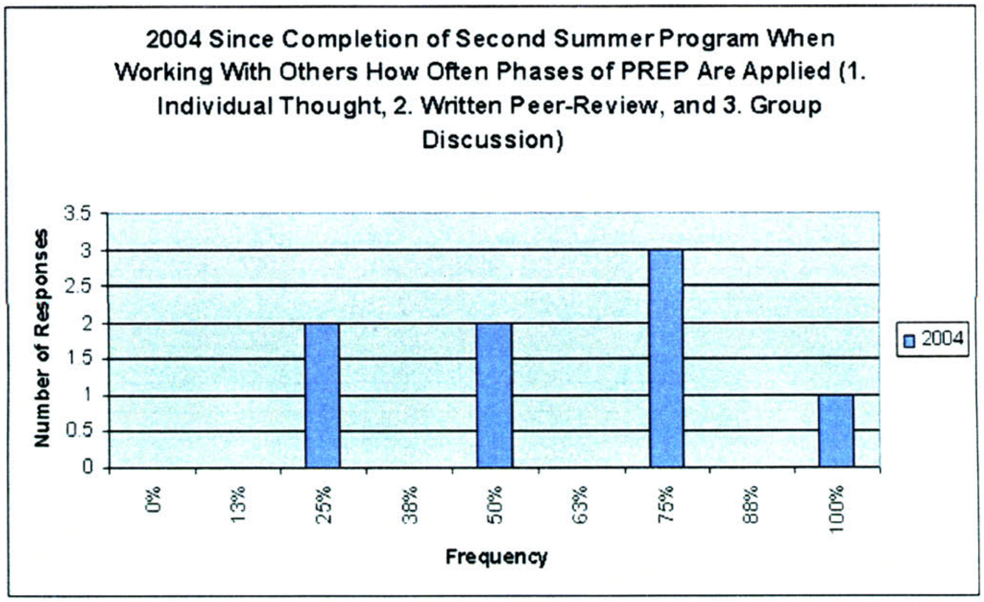
Year 2003 - 28 Students, 5 Responses



	Frequency
2003 Average	45.83%
2003 Unbiased Standard of Deviation	24.58%
2001-2006 Average	54.92%
2001-2006 Unbiased Standard of Deviation	26.51%

Appendix B Figure 75: Since Program How Often Apply PREP When Working With Others, Second Summer 2003

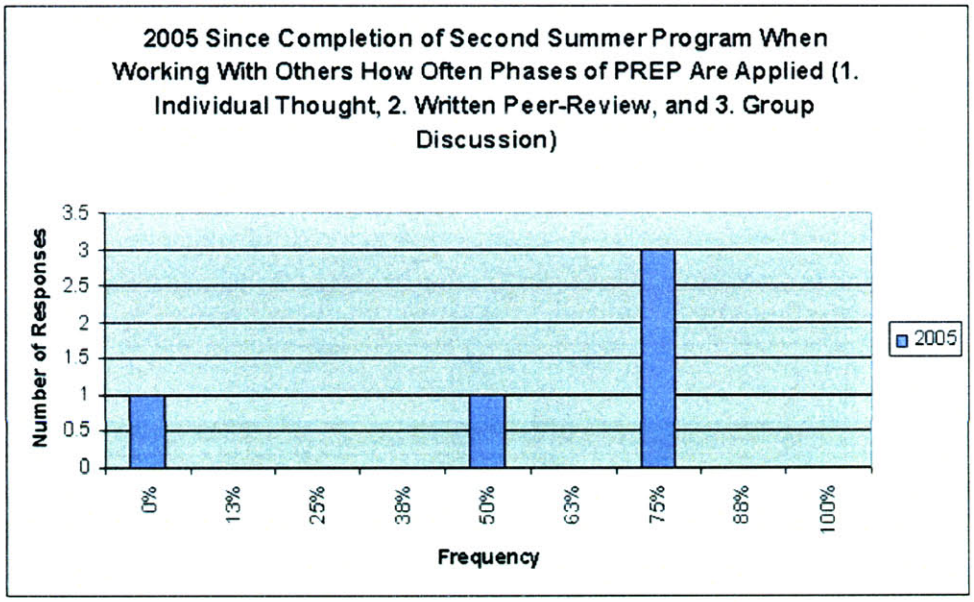
Year 2004 - 29 Students, 8 Responses



	Frequency
2004 Average	59.38%
2004 Unbiased Standard of Deviation	26.52%
2001-2006 Average	54.92%
2001-2006 Unbiased Standard of Deviation	26.51%

Appendix B Figure 76: Since Program How Often Apply PREP When Working With Others, Second Summer 2004

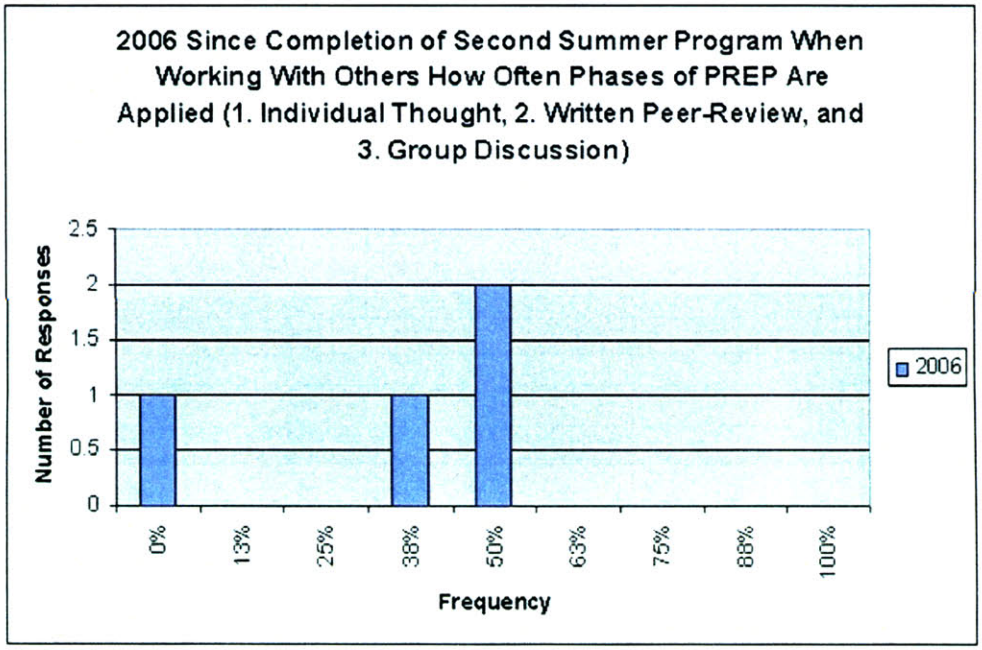
Year 2005 - 19 Students, 5 Responses



	Frequency
2005 Average	55.00%
2005 Unbiased Standard of Deviation	32.60%
2001-2006 Average	54.92%
2001-2006 Unbiased Standard of Deviation	26.51%

Appendix B Figure 77: Since Program How Often Apply PREP When Working With Others, Second Summer 2005

Year 2006 - 10 Students, 4 Responses



	Frequency
2006 Average	34.38%
2006 Unbiased Standard of Deviation	23.66%
2001-2006 Average	54.92%
2001-2006 Unbiased Standard of Deviation	26.51%

Appendix B Figure 78: Since Program How Often Apply PREP When Working With Others, Second Summer 2006

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